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Operation and Maintenance of Particulate Control Devices in Kraft Pulp Mill and Crushed Stone Industries

PEDCo-Environmental Specialists, Inc, Cincinnati, OH

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Operation and Maintenance of Particulate Control Devices in Kraft Pulp Mill and Crushed Stone Industries

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ABSTRACT

Control of fine particulate emissions from selected kraft pulp mill and stone crushing facilities is addressed. The principal devices considered are electrostatic precipitators, wet scrubbers, and fabric filters. Guidelines are provided for industrial personnel responsible for selection of an appropriate control device. Information on the operation and expected performance of conventional air pollution control devices is based on current design practice, theoretical design models, reported performance, cost predictions, and published information.

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METRIC CONVERSION FACTORS

To convert English units	Multiply by	To obtain SI units
British thermal unit (Btu)	1054	Joule (j)
Cubic foot (ft^3)	0.0283	Cubic meter (m^3)
Degrees fahrenheit	5/9 (°F-32)	Degrees Celsium (C)
Foot	0.3048	Meter (m)
Gallon (U.S. Liquid)	0.0038	Cubic meter (m^3)
Gallon (U.S. Liquid)	3.7854	Liter (l)
Grain (gr)	0.06479	Gram (g)
Horsepower (hp)	746.0	Watt (w)
Inch	0.0254	Meter (m)
Inch	2.54	Centimeter (cm)
Inches of water	248.8	Pascal (pa)
Pound	0.4536	Kilogram (kg)
Ton, short	0.9072	Metric ton(kkg)

Some Common Physical Constants

Boltzmann's constant	$k = 1.3805 \times 10^{-23}$ J/°K
Gravitational acceleration	$g = 9.807$ m/s^2
Universal gas constant	$\bar{R} = 8.304$ J/mol-°K
Electron volt	$eV = 1.602 \times 10^{-19}$ J
Standard temperature =	1.013×10^5 Nt/m^2
and pressure (STP)	and 273.15°K

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The project director was Mr. Richard W. Gerstle, and the project manager was Mr. Michael F. Szabo. PEDCo Environmental, Inc., as the primary contractor and editor, directed and coordinated the project and also provided technical information.

Cottrell Environmental Sciences researched and coordinated the information on electrostatic precipitators and wet scrubbers. The work was managed and executed by Mr. David V. Bubenick with the help of Mr. Chin T. Sui, Dr. P.D. Paranjpe, and Mr. Manuel Canton. The CES effort was directed by Drs. Paul L. Feldman and Richard S. Atkins.

Midwest Research Institute evaluated the fabric filtration systems. Principal investigator was Mr. Mark A. Golembiewski, assisted by Mr. V. Ramanathan. Program supervision was provided by Dr. K.P. Ananth.

SECTION 1

INTRODUCTION

1.1 PURPOSE OF REPORT

This report is intended to provide guidelines by which environmental control personnel in the kraft pulp mill and crushed stone industries can (1) determine which type of particulate control device is best for a certain process, (2) follow operational and maintenance practices that will maintain high particulate collection efficiencies and minimize malfunctions, and (3) relate the total mass efficiencies of control devices to their efficiencies for collection of particulate in specific size fractions.

1.2 SIGNIFICANCE OF PARTICULATE EMISSIONS

Many undesirable effects have been related to the discharge of particulate matter into the atmosphere. Particulates constitute a health hazard, cause poor visibility, function as a transport vehicle for gaseous pollutants, and (in many cases) are highly active both chemically and catalytically.[1]

The full effects of submicron particulates on health are not yet well defined. They are regarded as constituting a whole category of pollutants rather than being a single pollutant. Once dispersed, they behave (depending on size) similarly to coarse particles and gases. They remain suspended and diffused, are subject to Brownian motion, follow fluid flow around obstacles, and can penetrate deep into the respiratory system.

Particles larger than 5 μm diameter are deposited in the nasal cavity or nasopharynx. Increasing numbers of smaller particles, so minute that they are difficult to measure, reach the lungs. More than 50 percent of particles between 0.01 and 0.1 μm that penetrate the pulmonary compartment are deposited in the lungs. This tendency to penetrate and be captured in the respiratory system is more a function of the geometry of the particles than of their chemical properties.

The unhealthy effects of these captured fine particulates are largely due to their chemical or toxic qualities, although the physical properties of certain long, fibrous materials may also irritate tissue. Many unknown factors remain, however, so it is unwise to generalize concerning the dangers of fine particulates.

1.3 SCOPE OF THE REPORT

This study deals with the following major emission sources in the kraft pulp and crushed stone industries:

Kraft pulp

- Recovery furnaces
- Lime kilns
- Smelt dissolving tanks
- Combination bark/fossil-fuel-fired boilers

Crushed stone

- Crushers
- Screens
- Transfer points
- Storage bins
- Drilling equipment

Information presented in this report was obtained from review of current literature, site visits, and personal communications with manufacturers and users of control equipment.

The following high-efficiency particulate control devices are evaluated: electrostatic precipitators (ESP's), wet scrubbers, and fabric filters (baghouses). Cyclone collectors, although not highly efficient, are evaluated to a limited extent, because of their historical use as a primary control device and their present use in controlling coarse particle size distributions.

In the kraft pulp mill industry, fabric filtration systems are not used to control particulate emissions from recovery furnaces, lime kilns, or smelt dissolving tanks. Emissions from these sources are controlled primarily by wet scrubbers or ESP's. All four of the control devices are used, however, on combination bark/fossil-fuel boilers.

In the crushed stone industry, fabric filters are used almost exclusively for controlling emissions from rock processing operations. Wet suppression techniques are used either separately or in conjunction with baghouses to limit fugitive emissions. Wet scrubbers are also used on stone crushing and conveying operations.

Section 2 provides descriptions of the subject processes and discussion of the extent of usage of conventional control devices to collect their particulate emissions. It then considers control system design parameters and basic design philosophies. Some correlations between design parameters are given, as well as estimates of capital and annual costs of each control device.

Section 3 describes the operation of each control device and the maintenance and operational procedures that contribute to operation at maximum efficiency with minimum downtime. The discussion encompasses startup, shutdown, normal operational procedures, and common malfunctions.

Fractional collection efficiencies of precipitators, wet scrubbers, and fabric filters are discussed in Section 4. Computer models are used to predict the fractional efficiency performance of dry precipitators and venturi scrubbers on kraft pulp mill and crushed stone operations. Almost no test data are available for comparison with the models. The fractional efficiency relationships of fabric filters are discussed only briefly because an appropriate computer prediction model is not available. Only one set of fractional efficiency test data were available for a mobile fabric filter.

Section 5 presents conclusions on the design, operation, maintenance, and the fractional efficiency capabilities of the particulate control devices, including a comparison of the advantages and disadvantages of applying each type of control device to the subject industries.

REFERENCES - SECTION 1

1. Oglesby, Sabert, Jr. Opening Remarks, EPA/Southern Research Institute Symposium on Electrostatic Precipitators for the Control of Fine Particles. EPA-650/2-75-016, Pensacola Beach, Florida, September 30 - October 2, 1974.

SECTION 2

CONTROL SYSTEMS: PARAMETERS AND CORRELATIONS

2.1 EMISSION SOURCES, CHARACTERISTICS, AND CONTROL SYSTEMS

Following is a brief discussion of the processes covered in this report, their particulate emission characteristics, quantities of emissions produced, and the types of conventional control devices used in each process.

2.1.1 The Kraft Pulping Process

A schematic diagram of the kraft (sulfate) pulping process is presented in Figure 2-1. The unit operations discussed in this report are limited to recovery furnaces, smelt dissolving tanks, and lime kilns. Although not shown in Figure 2-1, the power boiler is also considered an emission source if it is fueled (or partially fueled) by wood bark, chips, or coal (referred to in this report as a "bark/fossil-fuel" boiler).

Pulping is the conversion of fibrous raw materials such as wood, cotton, or recycled paper into a material suitable for use in paper, paperboard, or building materials. The principal source of fibers is wood. In the process, wood chips are cooked (digested) at an elevated temperature and pressure in "white liquor," a water solution of sodium sulfide (Na_2S) and sodium hydroxide (NaOH). The white liquor chemically dissolves lignin (the material that bonds the cellulose fibers together) from the

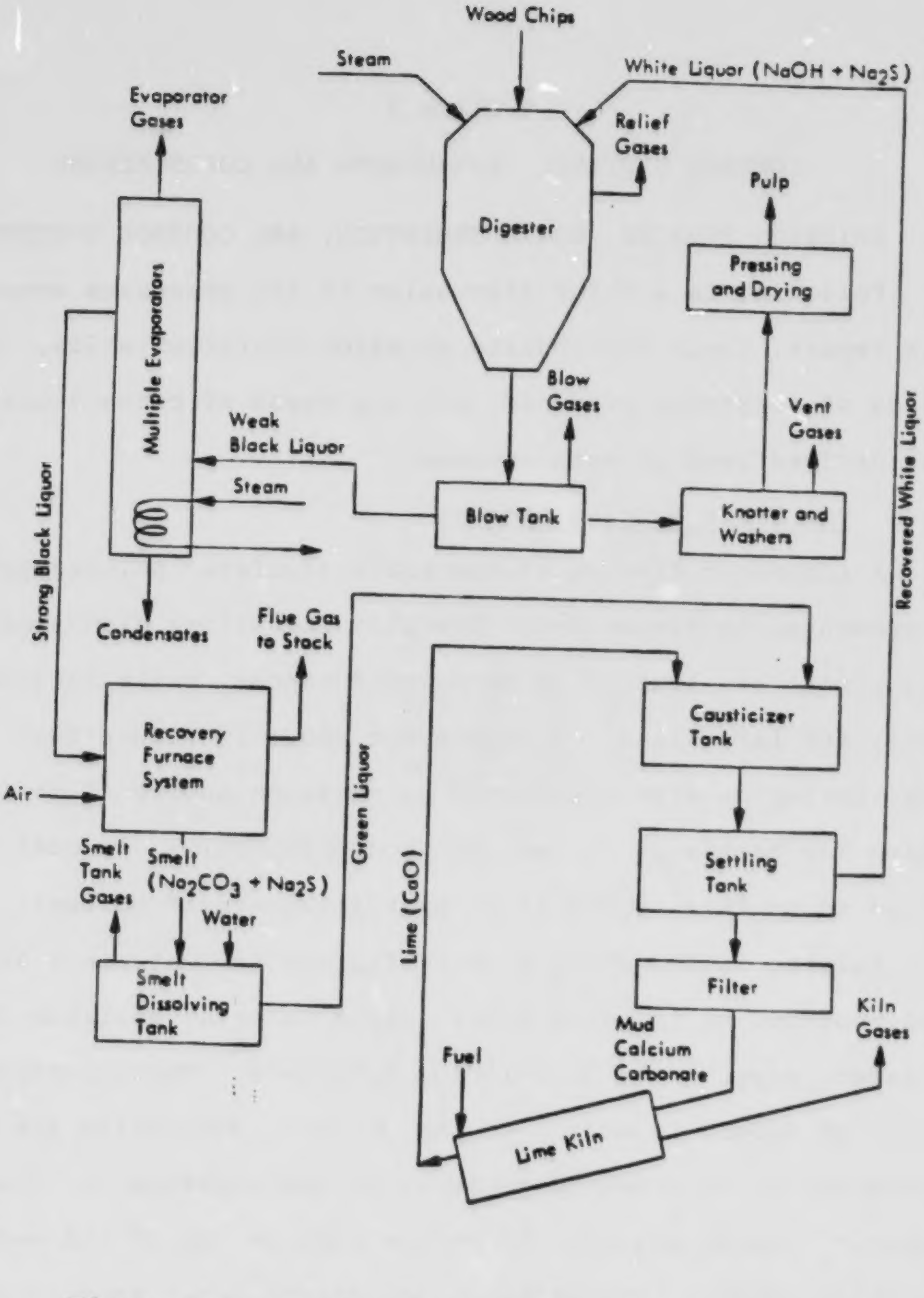

Wood Chips
Steam
White Liquor (NaOH + Na2S)
Relief Gases
Digester
Pulp
Pressing and Drying
Evaporator Gases
Multiple Evaporators
Blow Gases
Vent Gases
Weak Black Liquor
Steam
Blow Tank
Knotter and Washers
Recovered White Liquor
Strong Black Liquor
Condensates
Flue Gas to Stack
Recovery Furnace System
Air
Green Liquor
Causticizer Tank
Settling Tank
Smelt Tank Gases
Smelt (Na2CO3 + Na2S)
Water
Lime (CaO)
Smelt Dissolving Tank
Filter
Kiln Gases
Mud Calcium Carbonate
Fuel
Lime Kiln

Figure 2-1. Kraft pulping process.

wood. The remaining cellulose (pulp) is filtered from the spent cooling liquor, washed with water, and made into paper.

The balance of the process is designed to recover both cooking chemicals and heat. Spent cooling liquor and the pulp wash water are combined to form a weak black liquor, which is concentrated to about 65 percent solids in multiple-effect evaporators, then fired in a recovery furnace. Two main types of recovery furnace systems are used in the industry: the direct-contact evaporator system and the newer indirect-contact or "low odor" system. To minimize total reduced sulfur (TRS) emissions from the conventional direct-contact system, the concentrated black liquor must be oxidated before it is combusted in the recovery furnace. Combustion of the wood lignin dissolved in the black liquor provides heat for generating process steam and converting sodium sulfate (Na_2SO_4) to sodium sulfide (Na_2S). To make up for chemicals lost in the operating cycle, salt cake (sodium sulfate) is usually added to the concentrated black liquor before it is sprayed into the furnace.

The smelt, consisting of sodium carbonate (Na_2CO_3) and sodium sulfide, is dissolved in water to form green liquor, which is transferred to a causticizing tank, where quicklime (CaO) is added to convert the sodium carbonate to sodium hydroxide. Formation of the sodium hydroxide completes the regeneration of white liquor, which is returned to the digester. A calcium carbonate mud precipitates from the causticizing tank and is calcined in a kiln to regenerate quicklime. The condensate streams from the digester system and multiple-effect evaporator system usually contain dissolved TRS gases. These gases may be removed with a condensate stripping system, using either air or steam in a stripping column, before these streams are discharged to the atmosphere.

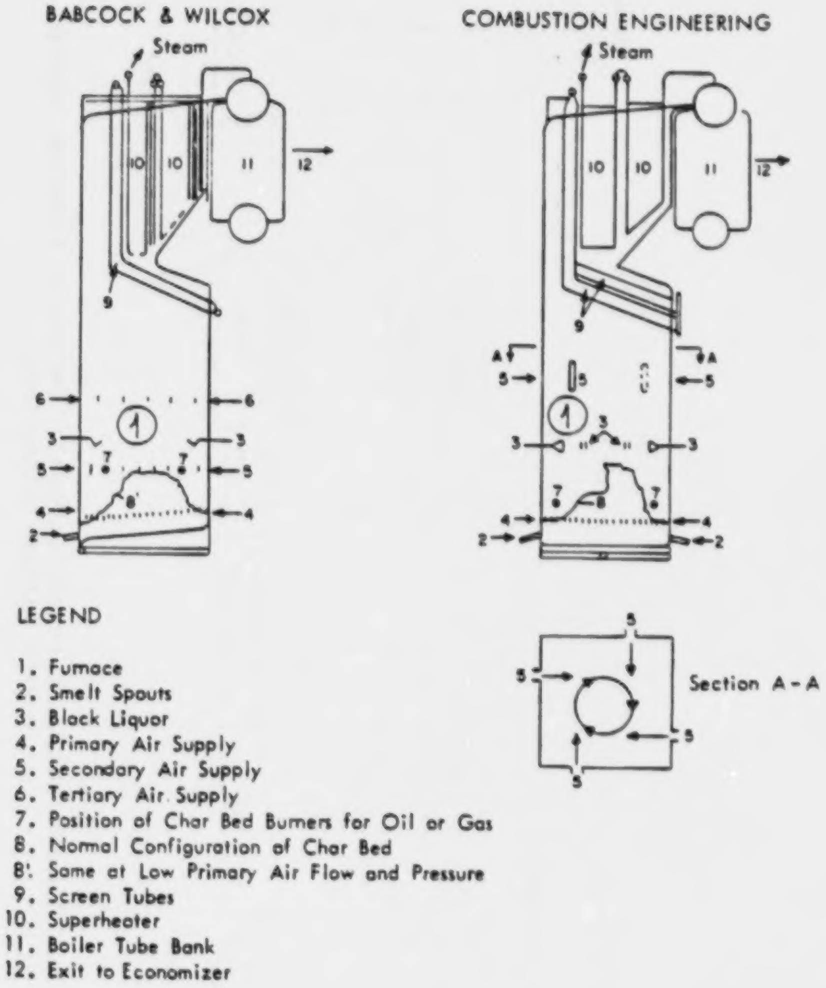
Recovery Furnaces--

In the recovery furnace, concentrated black liquor is burned to produce a smelt of sodium carbonate and sodium sulfide, which is used to reconstitute cooking liquor. Steam is a byproduct of this operation. As shown in Figure 2-2, the furnace consists of a combustion chamber and heat recovery equipment (located directly above). The rising flue gases pass through a superheater section, the boiler tube bank, and an economizer section before exiting to the contact evaporator unit.

One of the two main types of recovery furnace systems used in the industry incorporates a direct-contact evaporator in the final stage of black liquor evaporation; it is called a conventional or direct-contact system. (See Figure 2-3). The other main type is an indirect-contact, direct-fired, or "low odor" system. (See Figure 2-4). About 75 percent of the new furnaces installed in the past 5 years are of this latter design.

Smelt Dissolving Tanks--

The smelt dissolving tank is a large vessel (3000 to 5000 ft^3) located below the recovery furnace. A molten mixture, comprised primarily of sodium sulfide and sodium carbonate (smelt), is removed continuously removed from the floor of the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COMBUSTION ENGINEERING
Steam
Steam
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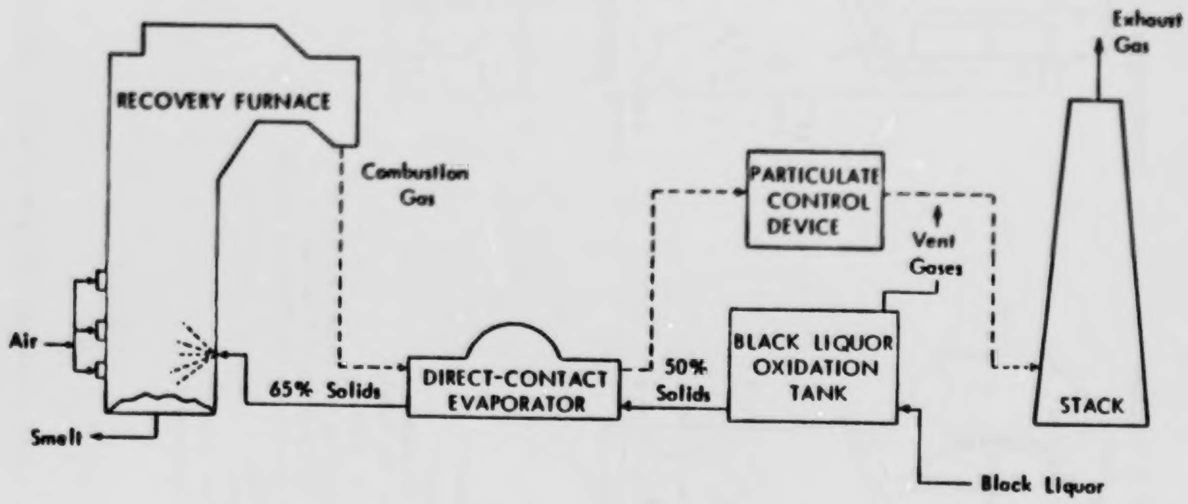
Section A - A
LEGEND
1. Furnace
2. Smelt Spouts
3. Black Liquor
4. Primary Air Supply
5. Secondary Air Supply
6. Tertiary Air Supply
7. Position of Char Bed Burners for Oil or Gas
8. Normal Configuration of Char Bed
8'. Same at Low Primary Air Flow and Pressure
9. Screen Tubes
10. Superheater
11. Boiler Tube Bank
12. Exit to Economizer

Figure 2-2. Principal design of recovery boiler furnace.[2]



RECOVERY FURNACE
Combustion Gas
Air
Smelt
65% Solids
DIRECT-CONTACT EVAPORATOR
50% Solids
PARTICULATE CONTROL DEVICE
Vent Gases
BLACK LIQUOR OXIDATION TANK
Black Liquor
STACK
Exhaust Gas

Figure 2-3. Direct-contact (conventional) recovery furnace system with black liquor oxidation.

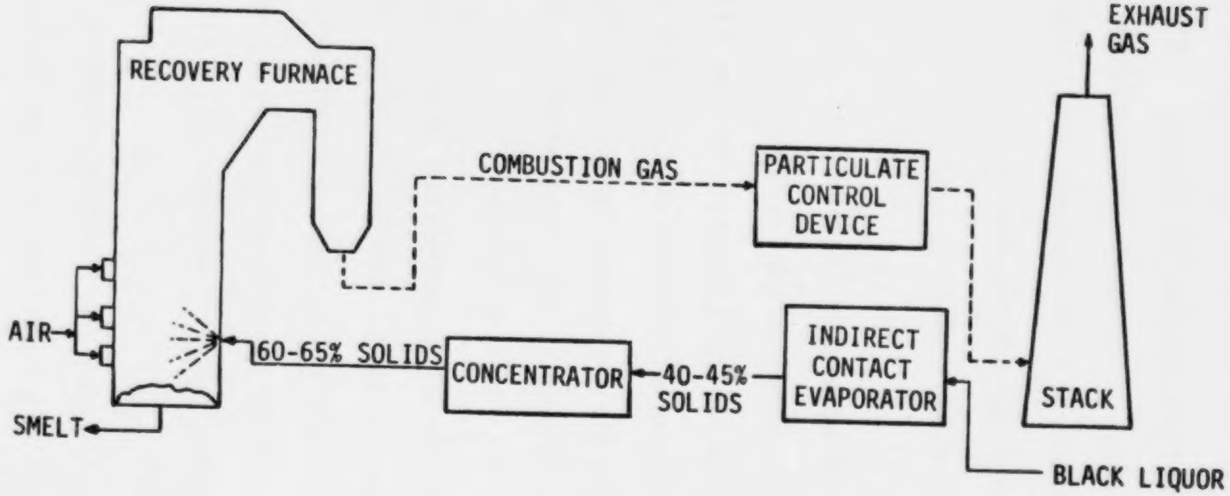

RECOVERY FURNACE
AIR
SMELT
60-65% SOLIDS
CONCENTRATOR
40-45% SOLIDS
INDIRECT CONTACT EVAPORATOR
BLACK LIQUOR
COMBUSTION GAS
PARTICULATE CONTROL DEVICE
STACK
EXHAUST GAS

Figure 2-4. Indirect-contact recovery furnace system.

recovery furnace. Water is added to this molten mixture in the smelt dissolving tank to produce green liquor. This tank is an open vessel equipped with an agitator to assist dissolution and a steam or liquid shatterjet system to break up the smelt stream before it enters solution. Entrained particulates are emitted with large volumes of steam as the molten smelt and water mix. The smelt dissolving tank is one of the main sources of particulate matter in a kraft pulp mill.

Lime Kilns--

The lime kiln is an essential element of the closed-loop system that converts the green liquor solution of sodium carbonate and sodium sulfide to white liquor. In the kiln the lime mud (calcium carbonate that precipitates from the causticizer) is calcined to produce calcium oxide (quicklime, CaO) for recausticizing the green liquor. The lime sludge typically enters as a slurry with 55 to 60 percent solids.

The kraft pulping industry generally uses large rotary kilns capable of producing 40 to 400 tons/day of quicklime. Fluidized-bed calciners are being used at four pulp mills, but their current production rate is less than 150 tons/day and accounts for only about 1 percent of the total quicklime produced in the kraft industry.[1]

The rotary kiln turns at low speeds, causing the lime to proceed downward toward the high-temperature zone (1800° to 2000°F), which is sustained by combustion of natural gas or fuel oil. The lime mud dries as it moves along (often aided by chains). Baffles in the upper section of the kiln are sometimes used to provide better contact with the hot gases. Near the lower end of the kiln, the lime agglomerates into small pellets, and finally is calcined to calcium oxide in the high-temperature zone near the burner.

These lime kilns differ from those used in the lime manufacturing industry in that the calcium carbonate is generally fed as a mud (sludge) containing 40 to 45 percent water instead of as a solid (limestone). This sludge contains a small percentage of sodium sulfide, which affects the size distribution and composition of the particulate in the exhaust gases. The limestone used in the lime industry does not contain sodium sulfide.

Bark/Fossil-Fuel Power Boilers--

Based on 1972 figures compiled by the American Paper Institute, about 7 percent of the total energy requirement of the pulp and paper industry is supplied by combustion of wastewood and bark, an additional 33 percent is supplied by combustion of its waste pulping liquors, and the remainder is provided by fossil fuels or by purchased electricity.[2]

According to a 1970 survey, 32 percent of the reporting pulp and paper mills used bark plus other fuels in their power boilers. On a Btu basis, the average fuel utilization for a group of 26 mills that reported emission data was as follows: bark/wood, 48.5 percent; oil, 31.0 percent; coal, 11.3 percent; and gas, 9.2 percent.[3]

Wastewood- and bark-fired power boilers can burn wood alone or can be modified to burn other fuels on an auxiliary basis or in combination. In power boilers, wastewood and bark are burned on chain grates in a radiant Dutch-oven-type boiler or in a horizontal, air-blown, suspended firing configuration in a vertical Stirling boiler. Wood handling systems (including hammermill grinding to a given particle size for suspended firing), bottom and fly ash handling systems, and underfire and overfire air controls must be provided. Major fuel characteristics affecting the design of wastewood-fired power boilers include ash and moisture content, particle size variations, and fixed and volatile carbon content.

The net heating value of most wastewoods is about 7200 to 9000 Btu/lb of dry wood or 3600 to 5400 Btu/lb on an as-fired basis. The heating value of wastewoods tends to vary with wood species. The presence of extractive materials such as terpenes and tall oils can substantially add to the energy content of the wood.[2]

2.1.2 Emission Characteristics - Kraft Pulping

Characteristics of emissions from the various sources discussed above are summarized in Tables 2-1 and 2-2. The average U.S. pulp mill emits about 5.5 lb of particulate per ton of air-dried pulp (ADP). A well-controlled mill emits about 2.8 lb/ton ADP. Nationwide, particulate emissions from kraft pulp mills run about 89,000 tons/yr. This amount would be reduced by about 49 percent if the best available control systems were applied to recovery furnaces, lime kilns, and smelt dissolving

Table 2-1. TYPICAL GAS CHARACTERISTICS IN KRAFT PULP MILL PROCESSES[1,3]

Emission source	Gas temperature °F	Flow rate, scfm	Moisture content, %	Uncontrolled particulate emissions,	
				gr/scf	lb/ton
Recovery furnace					
Conventional	250-360	32,000-120,000	25-35	3.8	180
Low odor	340-450	114,000-400,000	7-20	4.7-8	
Smelt dissolving tank	160-230	11,000-22,000	35-45		8.0
Lime kiln	400-500	15,000-66,000	25-35	9.7	80

Table 2-2. CHARACTERISTICS OF PARTICULATE EMISSIONS FROM SELECTED U.S. POWER BOILERS[3]

Number of boilers	Percent of fuel supplied (Btu basis)				Particulate concentration (uncontrolled), gr/ft^3
	Coal	Oil	Gas	B/W[a]	
18	100	0	0	0	1.87
2	100	0	0	0	
2	100	0	0	0	4.89
16	0	46	0	54	3.47
2	75	0	0	25	
2	0	0	62	38	2.30
2	73	16	0	11	
3	0	25	39	36	1.88
2	0	0	0	100	1.40

[a] B/W = bark and wastewood.

tanks.[1]

Except for those from power boilers, particle size data are generally lacking on emissions from kraft pulping operations. Uncontrolled emissions from each process are discussed next.

Recovery Furnaces--

The flue gas from black liquor recovery boilers contains considerable particulate matter, which is formed by the release of sodium from the smelt bed to the flue gas above it. The amount of sodium released appears to depend not on the sodium content of the black liquor dry solids, but rather on partial vapor pressures and diffusion conditions. Characteristics of emissions from conventional versus low order recovery furnaces are discussed below.

The primary difference in the low odor recovery furnace operation as compared to the conventional process is the elimination of direct contact between the concentrated black liquor and the recovery boiler gases. In general, the black liquor leaving the evaporator at 45-50 percent solids is further condensed to 60-65 percent solids is a concentrator. It is then piped directly to the recovery boiler.

Particulate emissions from a conventional recovery furnace prior to application of a direct-contact evaporator or a control device normally range from 8 to 12 gr/dscf (200 to 450 lb/ton ADP). A direct-contact evaporator acts as a particulate control device and reduces particulate emissions from a furnace system by about 50 percent. Particulate emissions from uncontrolled conventional recovery furnace systems currently in operation average about 3.81 gr/dscf[1] versus about 7.93 gr/dscf for low odor boilers. Particulate matter emitted from the recovery furnace consists of sodium sulfate and sodium carbonate and may contain small amounts of sodium chloride. Sodium chloride will be present if the pulpwood has been stored in saline water or if the makeup chemicals contain chloride impurities.

Flue gas volume flow rates from recovery furnaces in general can range from 32,000 to 400,000 scfm depending on pulp production rate and volume of excess air used. Temperatures of the exiting gases (after economizer) fall in the range of 250° to 360°F for the conventional process versus 340°-450°F for the low odor process.

The conventional kraft recovery furnace is also one of the largest emitters of reduced sulfur compounds in the pulping process. Concentrations of sulfur dioxide (SO_2) in the furnace exhaust gases may be as high as 880 ppm.[1]

Smelt Dissolving Tanks--

Particulate consisting of dissolved and undissolved NaOH, Na_2CO_3, and Na_2S is emitted from the dissolving tank with the vented gases. Uncontrolled emissions from a typical tank (1000 tons of pulp/day) may be as high as 380 lb/h (8.0 lb/ton ADP).[1] Exhaust gas flow rates may range from 11,000 to 22,000 scfm at 160° to 230°F.

Lime Kilns--

Lime kiln particulate emissions consist principally of sodium salts, calcium carbonate, and calcium oxide. Because the sodium salt (soda fume) emissions result primarily from sodium compounds that are retained in the mud because of inefficient or incomplete washing, particulate emissions are affected by the efficiency of the mud washing system (higher than normal sodium levels in mud result in higher particulate emissions). The calcium particles result from entrainment; thus, emissions are affected by the gas velocity and turbulence in the kiln. Uncontrolled particulate emissions from a typical lime kiln can range from 3 to 15 gr/scf, with exhaust volumes of 15,000 to 66,000 scfm. Gas temperatures are usually about 400° to 500°F. The dust losses constitute about 1 to 5 percent of the total dry solids load to the kiln.[1]

The rolling and tumbling of the lime in the rotary kiln and the vaporization of sodium compounds (carried into the kiln with the lime mud) in the high-temperature zone and their later condensation are responsible for formation of most of the particulate matter in the kiln exhaust gases. In addition to being an air pollution problem, these emissions constitute a loss of usable chemicals.[2]

The lime dust, made up of particles ranging from 1 to over 100 μm in diameter, is removed from the exhaust gas quite easily. The soda fume consists of very small particles (most less than 1 μm in diameter) and is very difficult to remove.[3]

Bark/Fossil-fuel Boilers--

The major potential air pollutant from wood-fired power boilers in the pulp and paper industry is particulate matter, which can result either from inorganic ash in the wood or from incomplete combustion.

Particulate emissions from wastewood combustion vary with ash content and particle size of the material being burned. The ash content can vary from less than 1 to 20 percent by weight on an as-fired basis. The sizes and shapes of the wood particles being burned can influence the design of grating systems, the kind of firing, and the relative distribution of underfire and overfire air in the furnace. Furnace fouling often occurs when bark is fired, especially when it is fired with other fuels. Small amounts of minerals that are gathered in the fuel while it is stored in sea water or on ground can lower the ash softening temperature so that it becomes very sticky in the furnace and cannot be easily removed. The amount of particulate matter swept from the combustion chamber is normally greater from horizontal suspension firing units than from Dutch-oven-type units.

Characteristic uncontrolled rates of particulate emission from pulp mill power boilers were shown previously in Table 2-2. Emissions from boilers firing bark or a combination of bark and fossil fuels range from 1.4 to 3.5 gr/scf. Typical gas flow rates in these types of boilers range from 19,000 to 200,000 scfm at temperatures around 450°F.[2]

Particle size characteristics of emissions from bark/fossil-fuel boilers are presented in Table 2-3. Bark that has been soaked in salt water contains a much greater percentage of fine particles than does freshwater bark (60 to 70% particulate less

Table 2-3. TYPTCAL PARTICLE SIZE DISTRIBUTION OF FLY ASH FROM BARK/FOSSIL-FUEL BOILERS[a]

A. Boiler fired with 100% bark

Particle size range, μm	Percentage by weight[b]	
	Flue gas	Stack gas after cyclone
<5	19.76	38.93
5 - 10	11.56	16.57
10 - 20	8.67	13.25
20 - 50	4.82	8.28
50 - 104	3.37	5.80
104 - 147	16.24	9.05
147 - 175	3.65	1.54
175 - 590	17.09	2.71
>590	12.77	1.25
Total	97.93	97.38
Other[c]	2.07	2.62

B. Boiler fired with 40% bark - 60% coal

Particle size range, μm	% by weight
+60	8.5
40-60	7.5
30-40	8.0
20-30	13.0
15-20	9.0
10-15	14.0
7.5-10	9.0
5.0-7.5	10.0
3.5-5.0	6.5
2.5-3.5	5.0
1.5-2.5	5.0
-1.5	4.5
Total %	100.0
% <10 μ	31.0

[a] Particle size range by Bahco method assuming a spherical particle and a specific gravity of 2.5.

[b] Average of two sampling runs.

[c] Due to handling loss.

than 1.0 µm in diameter in high salt fuel). Potential gaseous emissions are oxides of nitrogen, oxides of sulfur, and hydrocarbons resulting from volatilization of the bark. The nitrogen oxide emissions are generally lower than those from fossil-fuel-fired boilers because of the larger combustion volumes per unit amount of fuel burned, the normally higher excess air levels (50 percent or more), and the higher fuel moisture content that results in low flame temperatures of 1800 to 2200°F. Emissions of SO_2 from bark-fired boilers generally are low because the sulfur content of bark is normally less than 0.1 percent by weight. Emissions of terpenes, hydrocarbons, and other volatile organic constituents as a result of distillation and incomplete combustion vary with wood species, furnace temperature, and retention time. The potential of these emissions as air pollutants has not been fully described.[3]

2.1.3 Control Methods - Kraft Pulping

The methods of emission control used at kraft pulp mills are presented in the following paragraphs.

Recovery Furnaces--

Nearly all recovery furnaces are equipped with electrostatic precipitators for primary particulate control. The degree of control provided, however, varies among the individual units. Design efficiencies range from about 90 percent on older precipitators to above 99.5 percent on recent installations. The lower efficiencies on older units were established by balancing the value of the recovered soda ash to the capital outlay and operating expenses of the ESP.

Until recently, almost all recovery furnace systems incorporated a direct-contact evaporator. Although the purpose of the evaporator is to concentrate black liquor, it also scrubs particulate matter from the gas stream. Depending on the type of direct-contact evaporator used, it can remove up to 50 percent of the particulate.

Most mills use direct-contact evaporators of the cascade type. The furnace gases pass over a trough filled with black liquor, which is scooped up by a rotating paddle wheel and then cascaded through the gas stream. Some mills use cyclones or venturis as the direct-contact evaporator. In these installations the black liquor serves as the particulate scrubbing liquid. Sometimes two venturis are used in series to increase particulate collection, precluding the need for an electrostatic precipitator.

On some recovery furnaces, scrubbers have been installed downstream from the precipitators. In the United States this practice has been confined to upgrading of existing units.

No applications of fabric filtration have been reported for particulate emission control on recovery furnaces. Because the emitted matter is sticky, the filter bags would quickly become blinded. Mechanical dust collectors are also unsuitable for this application because of the small particle size of the particulate.

Information on Research Cottrell precipitators on kraft pulp mill recovery boilers is presented in Appendix A-1.

Smelt Dissolving Tanks--

The gases from most smelt dissolving tanks are vented through mist eliminator pads with fine wire mesh screens about 1 ft thick. Mist eliminator pads are basically low-energy scrubbers with collection efficiencies of about 80 percent. Droplets condensing from the gas collect on the screen and are back-flushed with water sprays to the dissolving tank. Several dissolving tanks are equipped with more efficient water scrubbers, such as low-pressure drop venturis (6 to 8 in. of water), packed towers, and cyclones with water sprays. Efficiencies of these systems run about 95 percent. A few mills combine the dissolving tank gases with the recovery furnace gases and send both streams to an electrostatic precipitator.

Lime Kilns--

The major ways of controlling particulate emissions from lime kiln and fluidized-bed calciner exhaust gases are liquid scrubbing (using either an impingement or a venturi-type scrubber) and recently, electrostatic precipitation. Scrubbing devices are usually located after a mechanical cyclone collector.

Most lime kilns at kraft pulping plants are controlled with venturi scrubbers with pressure drops ranging from 10 to 25 in. H_2O. These systems provide collection efficiencies of up to about 99 percent. A few kilns are controlled by impingement scrubbers with wetted baffles and water sprays. These scrubbers have pressure drops of 5 to 6 in. H_2O and provide collection efficiencies of only about 90 percent.[1]

Some kilns in Sweden are controlled by electrostatic precipitators. Design efficiencies are about 99 percent. One U.S. mill has a retrofitted precipitator serving three kilns.

Fabric filtration is not used as a control method for lime kiln emissions because of the moisture content (25 to 35%) of the exhaust gases.

Bark/Fossil-fuel Boilers--

Control of particulate emissions from wood and bark/fossil-fuel boilers normally is not as complex as control of emissions from other processes within the pulp and paper industry. The problems and solutions are similar to those in conventional boilers.

The particulates from bark firing are often large, 5 to 10 μm or greter. Because their specific gravity is usually low, the use of mechanical cyclone collectors is not always effective. Electrostatic precipitation of the fly ash is difficult because the high carbon content can cause low particle resistivity. Minerals in the bark can cause abrasion in the collecting equipment and ducts and resultant rapid metal wear. More complete analysis and classification of the chemical composition and physical size characteristics of particulate matter emitted from bark-fired power boilers are needed.

Electrostatic precipitators have been installed on only a few bark/fossil fuel fired boilers but have shown collection efficiencies as high as 99.9 percent, (bark/coal fired boiler). Cyclone collectors offer less efficient, but also less expensive, control for bark/fossil fuel boilers, and wet scrubbers or fabric filters (which are effective for removal of particles below 5 μm) offer an alternative to electrostatic precipitation.

Granular bed scrubbers have also reportedly been used successfully on a number of non-salt hogged fuel boilers. However, efficiency of the granular bed scrubbers falls off rapidly for particles less than about 2 micrometers in diameter. The Simpson Timber Co. in Shelton, Washington rejected the granular bed scrubber for use in controlling salt laden particulate from its hogged fuel boilers because the scrubber would not remove the blue haze caused by the primarily sub-micron salt particles.

Since the granular bed scrubber is not an efficient collector of fine particles, and has not been fully developed, a detailed discussion of this device is not included in this report.

Two pulp mills in the State of Washington use fabric filtration systems to control emissions from their power boilers. Both fire 100 percent bark and wastewood.

The Simpson Timber Company in Shelton uses two fabric filters to reduce particulate emissions from their two power boilers. Both are equipped with Teflon B-coated fiberglass bags. The units handle 100,000 and 130,000 acfm at about 500°F. Both collectors are preceded by mechanical collectors and were installed to remove submicron NaCl particles from the exhaust gases because the plant had experienced opacity problems with the plumes from the power boiler stacks. The air-to-cloth ratio (A/C) is 4.5/1; the pressure drop is about 9 in. H_2O. The collectors are cleaned by pulse-air action, and operating experience is described by plant personnel as reasonably good in the 2 years since installation.

The Long Lake Lumber Company in Spokane is the other pulp mill using fabric filtration for power boiler emission control. The fabric filter cleans approximately 17,200 acfm of effluent at 400°F and is equipped with Nomex bags that are cleaned by the pulse-jet method. A/C ratio is 4.0/1. This collector has reportedly been operating well for 3 years at a collection efficiency of 99.7 percent.

A Georgia-Pacific mill in Bellingham, Washington, has recently contracted Standard Havens to install a 180,000-acfm fabric filter to control particulate emissions from its four bark-fired power boilers. The unit will reportedly operate at a net A/C ratio of 4.0/1 and a temperature of about 440°F. It will be outfitted with Teflon-coated fiberglass bags. Georgia-Pacific selected a fabric filtration rather than a dry gravel bed system and venturi scrubber because they believe it to be the most reliable and proven means of control.

Two recent bark/oil-fired boilers equipped with venturi scrubbers are Crown Zellerbach's Port Townsend and Port Angeles plants near Seattle. The Port Townsend plant has a salt emissions problem because it fires sea-soaked bark; the Port Angeles plant does not. Both scrubbers are located downstream from a multiclone collector. The Port Townsend scrubber operates at pressure drops ranging from 15 to 20 in. H_2O, and outlet emissions have been tested at 0.07 to 0.18 gr/dscf depending on the salt content of the bark. Sodium chloride accounts for 26 to 70 percent of total emissions. The Port Angeles scrubber operates at pressure drops from 8 to 10 in. H_2O and outlet emissions have been measured at 0.022 gr/dscf. Thus, the Port Angeles scrubber achieves a lower emission rate at a lower pressure drop than the Port Townsend scrubber. Opacity of the Port Angeles stack also is very low. These differences in operation can be attributed in large part to the salt content of the hogged fuel burned at the Port Townsend plant, which cannot meet the 0.10 gr/dscf particulate emission regulation when the salt content of the fuel is greater than 1 percent.

A listing of bark/fossil-fuel fired boilers from the National Emission Data System (NEDS) is presented in Table A.1-2, Appendix A. A number of particulate scrubbers operating on bark/fossil-fuel boilers are summarized in Table A.1-3, Appendix A-1.

2.1.4 Crushed Stone Processing

The conversion of naturally occurring minerals into crushed stone products involves a series of interrelated physical operations. Quarrying, transporting, crushing, size classification, and drying are common to almost all methods of mineral production. Particulate air pollution may result from any or all of these operations. The dust emitted is usually a heavy particulate released at ambient temperature.[4]

The initial step in processing of crushed stone occurs at the quarry site. Blast holes are drilled vertically into the exposed stone faces and charged with explosives; the rock is then blasted out of its deposit. If secondary breakage is required, "drop ball" cranes are normally used. Oversize rock may also be reblasted. The broken rock is transported by 35- to 50-ton trucks from the quarry pit to the primary crusher, which is often in or near the quarry. When portable plants are located in the quarry itself, material can be fed directly to the primary crusher by a power shovel.

Crushing plant operations common to most crushed stone installations are primary crushing, scalping, secondary crushing, tertiary or finishing crushing, final screening, conveying, storage and shipping, and in some instances, washing. Depending on the purpose of the plant and the kind of rock processed, all or only a few of these operations take place.

As illustrated in the flowsheet in Figure 2-5, broken rock obtained from the quarry is dumped into a hoppered feeder, usually a vibrating grizzly type, and fed to the primary crusher for initial reduction. Jaw or gyratory crushers are normally used, although impact crushers are gaining favor for crushing low-abrasion rock (e.g., limestone) and when high reduction ratios are desired. The crusher product (normally in pieces 3 to 12 in. in size) and the "grizzly throughs" are discharged onto a belt conveyor and transported to a surge pile or silo for temporary storage.[5]

The material is then reclaimed, usually by a series of vibrating feeders under the surge pile, and conveyed to a scalping screen, which separates the process flow into three fractions

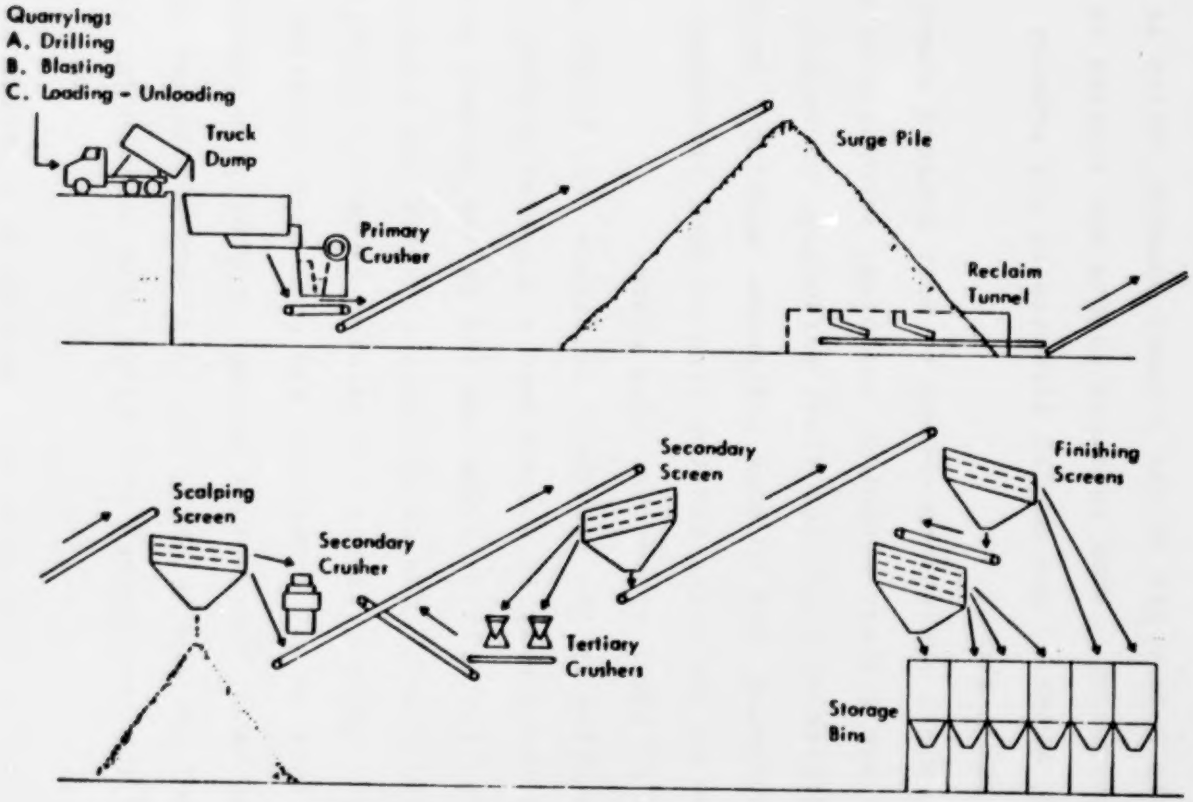

Quarrying:
A. Drilling
B. Blasting
C. Loading - Unloading
Truck Dump
Primary Crusher
Surge Pile
Reclaim Tunnel
Scalping Screen
Secondary Crusher
Secondary Screen
Tertiary Crushers
Finishing Screens
Storage Bins

Figure 2-5. Material flows through a typical crushed stone plant.

(oversize, undersize, and "throughs") prior to secondary crushing. The oversize is discharged to the secondary crusher for further reduction. The undersize, which requires no further reduction at this stage, normally bypasses the secondary crusher, thus reducing its crushing load. The "throughs," which contain unwanted fines and screenings, are usually removed from the process flow and stockpiled as crusher-run material. Gyratory or cone crushers are the most commonly used for secondary crushing, although impact crushers are used at some installations.[5]

At a typical operation the product from the secondary crushing stage (usually 1 in. or less in size) is transported to a secondary screen for further sizing. Sized material from this screen is conveyed or discharged directly to tertiary crushing, which takes place on cone crushers or hammermills. The product from the tertiary crushers is shuttled back to the secondary screen, forming a closed circuit with a fixed top size. The throughs from this screen are discharged to a conveyor and elevated to a screen house or tower containing multiple-screen lines for final sizing. At this point, end products of desired gradation are chuted directly to finished product bins or transported by conveyors or trucks to stockpiles in open areas.

Sometimes stone washing is required to meet particular end product specifications or demands, such as those for concrete aggregate. Washing plants consist of a number of fine mesh screens onto which the material falls and is sprayed with a heavy water-spray. Unwanted fines are usually discharged to a settling pond.

2.1.5 Emissions Characteristics - Crushed Stone

Particulates emanate from many sources (both process and fugitive) in a quarry and crushed stone plant. Process sources include drilling, crushing and grinding, conveying and elevating (transfer points), stockpiling (the actual operation itself), and screening. Fugitive emissions are generated by blasting, loading, hauling, stockpiling (e.g., free fall), and also are windblown from roads, plant yards, and stockpiles. No precise estimate of fugitive emissions has been made.

Quantitative data on emissions from these sources are practically nonexistent. The few data available are conflicting and, in some cases (such as when material balances are used) without basis. Examples of the ranges in the available emissions data and corresponding emission factors are presented in Table 2-4.

Examination of the data in Table 2-4 leads to several conclusions. First, emission factors do not take into account the kind of rock, which is a very important parameter. Second, in most cases reported emissions are considerably higher than the emission factors. Third, reported emission values are inconsistent with the operation performed and the corresponding emission factor. For example, the emission factor for secondary crushing and screening is three times that for primary crushing, but reported emissions from primary crushing are much higher than those for secondary.

Factors affecting emissions that are common to most crushed

Table 2-4. REPORTED UNCONTROLLED EMISSIONS VERSUS EMISSION FACTORS[4]

Operation	Reported emissions, lb/ton	Emission factors, lb/ton
Primary crushing	4.8 - 120	0.5
Secondary crushing and screening	0.26 - 13.7	1.5
Tertiary crushing and screening	3.6 - 18.2	6.0
Recrushing and screening	0.6 - 7.97	5.0
Screening, conveying, and handling	1.4 - 125	2.0

stone operations include moisture content of the rock, the kind and amount of rock processed, the equipment and operating practices, and a variety of geographical and seasonal factors. These factors apply to both fugitive and process sources associated with either quarrying or plant operations.

Minimal data are available to define the particle size characteristics of dust generated in stone processing operations. It is usually a fairly coarse particulate containing some moisture. Particle size depends on the kind of rock, the processing equipment, and the stage of processing. Figure 2-6 presents particle size data on emissions from a jaw crusher and a conveyor/screening operation. Less than 10 percent of the particles emitted from the crusher are smaller than 10 μm, whereas 50 percent of those conveyor/screening operations are below 10 μm.

Drilling (Quarrying)--

Emissions from drilling operations result primarily from air flushing to remove cuttings and dust from the bottom of the hole. Putting compressed air down the hollow drill center forces cuttings and dust up and out the annular space between the hole wall and drill. Factors affecting the level of uncontrolled emissions include the kind of rock, the moisture content of the rock, the type of drill, the diameter of the hole, and the penetration rate.

Crushing--

Generation of particulate emissions is inherent in the crushing process. Most apparent at crusher feed and discharge

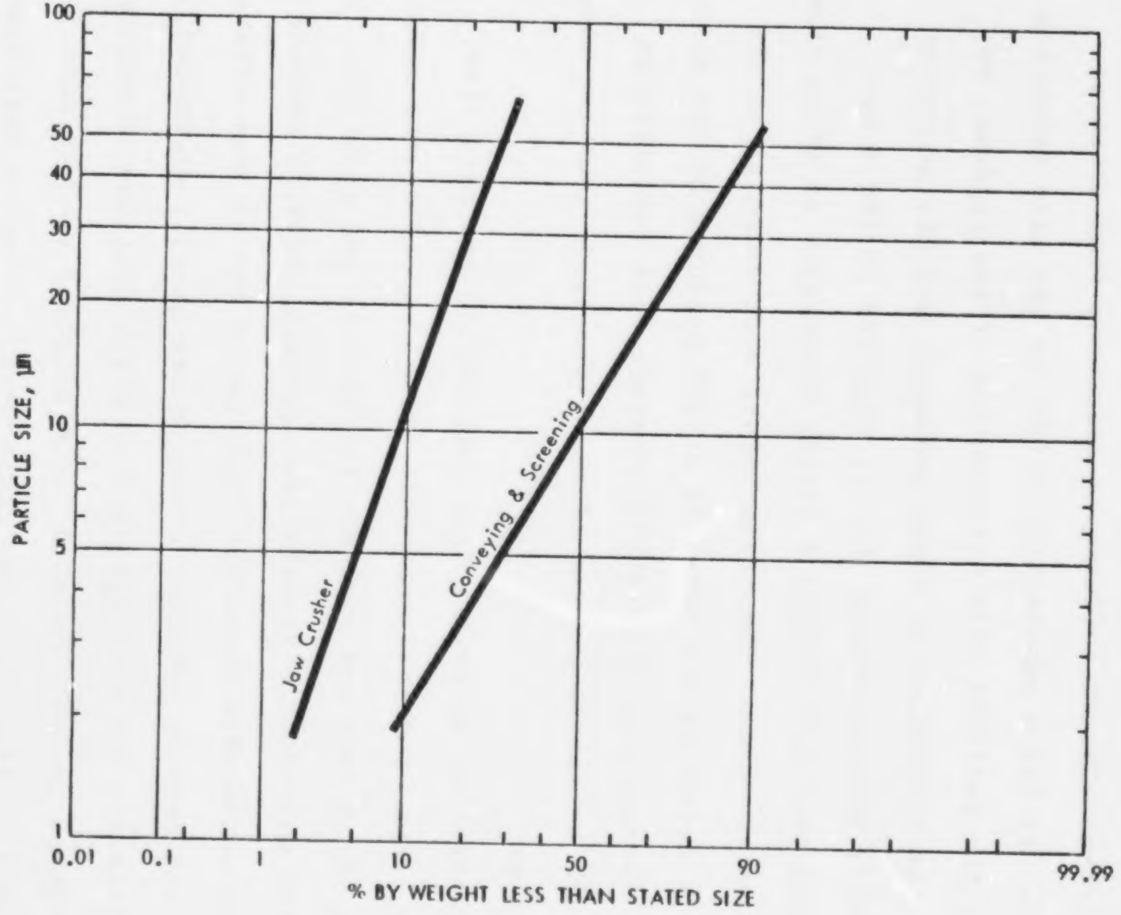


Figure 2-6. Particulate size distribution from rock processing operations.

point, the emissions are influenced by various factors, including the moisture content of the rock, the kind of rock, the processes, and the type of crusher.

The crushing mechanism (i.e. compression or impact) is the most important element influencing emissions from crushing equipment. It has a substantial effect on the size reduction achieved; the particle size distribution of the product, especially the proportion of fines produced; and the amount of mechanically induced energy that is imparted to the fines.

Impact crushers produce a larger proportion of fines than compression crushers. They also impart more velocity to the fines as a result of the fan-like action produced by the spinning hammers. Hence, impact crushers generate more uncontrolled particulate emissions per ton of stone processed than any other crusher type.

Uncontrolled emissions from compression crushers (jaw, gyratory, cone, and roll crushers) closely parallel the reduction stage to which they are applied; the greater the reduction, the higher the emissions. Primary jaw crushers probably produce more dust than comparable gyratories because of the bellows effect of the jaw and because gyratory crushers are usually choke-fed, which minimizes the open spaces from which dust can be emitted. In subsequent reduction stages, cone crushers produce more fines as a result of attrition, and consequently generate more dust.

Screening--

Dust is emitted from screening operations as a result of the agitation of dry stone. The level of uncontrolled emissions is dependent on the particle size of the material screened, the amount of mechanically induced energy transmitted, and other factors already discussed.

Generally, the screening of fines (less than 1/8 in.) produces more emissions than the screening of coarse sizes. Screens agitated at large amplitudes and high frequency emit more dust that those operated at small amplitudes and low frequencies.

Conveying (Transfer Points)--

Particulates may be emitted from any and all materials handling and transfer operations. As with screening, the level of uncontrolled emissions is dependent on the size of the material and how much it is agitated. Perhaps the worst case occurs at conveyor belt transfer points, where material is discharged from the conveyor at the head pulley or received at the tail pulley. The quantity of emissions depends on the conveyor belt speed and the free-fall distance between transfer points.

Storage Bins--

The transfer of final stone product to storage bins by conveyor belt or chute generates dust emissions similar to those from other transfer operations. Significant particulate emissions also may evolve from loadout of the stored material into open dump trucks. Again, the amount of dust generated depends on the moisture content of the stone and the free-fall distance.

2.1.6 Control Methods - Crushed Stone Operations

Because a typical stone crushing plant contains a multiplicity of dust-producing points, effective emission control is a complex and difficult problem. Methods for control of plant-generated emissions include wet scrubbers, wet dust suppression, dry collection, and a combination of both wet suppression and dry collection. In wet dust suppression, moisture is introduced into the material flow, causing fine particulate matter to be confined and remain with the material flow rather than to become airborne. Dry collection involves hooding and enclosing dust-producing points and exhausting emissions to a collection device. Combination systems (Figure 2-7) utilize both methods at different stages throughout a stone processing plant. The use of enclosed structures to house process equipment is also an effective control technique.[5]

In a wet dust-suppression system, dust emissions are controlled by spraying moisture (water or water plus a wetting agent) at critical dust-producing points in the process flow. This causes dust particles to adhere to larger stone surfaces or to form agglomerates too heavy to become, or remain, airborne. Thus, the objective of wet dust suppression is not to fog an emission source with a fine mist to capture and remove emitted particulates, but rather to prevent their emission by keeping the material moist at all process stages.

Small quantities of specially formulated wetting agents or surfactants are blended with water to reduce its surface tension and consequently improve its wetting efficiency so that dust particles may be suppressed with a minimum of added moisture.

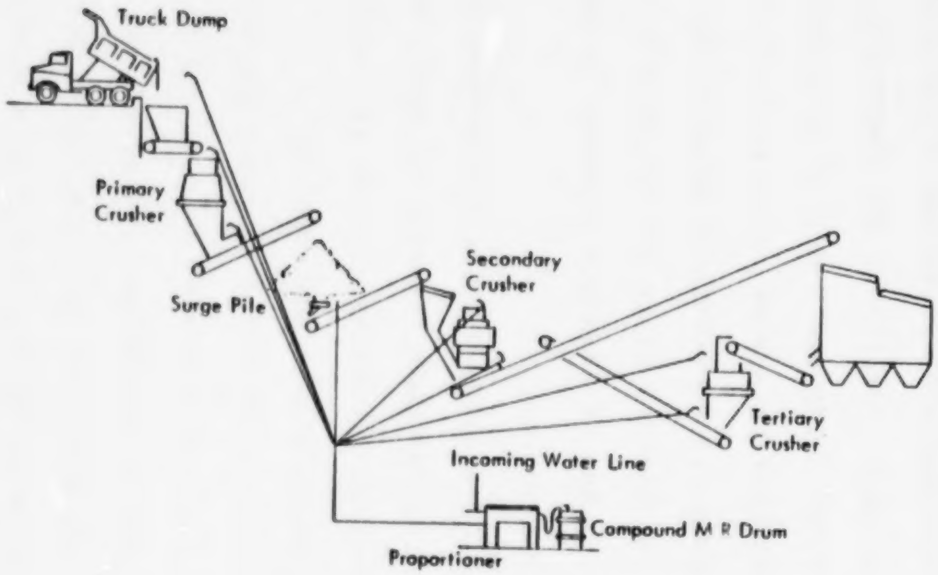

Truck Dump
Primary Crusher
Surge Pile
Secondary Crusher
Tertiary Crusher
Incoming Water Line
Compound M R Drum
Proportioner

Figure 2-7. Combination wet suppression dry collection systems.[5]

The dilution of such an agent in minute quantities in water (1 part wetting agent to 1000 parts water) is reported to make dust control practical throughout an entire crushed stone plant with as little as 1/2 to 1 percent total added moisture per ton of stone processed.[5]

A typical wet dust-suppression system illustrated in Figure 2-8, contains several basic components and features, including (1) a dust control agent (compound M-R), (2) proportioning equipment, (3) a distribution system, and (4) control actuators. A proportioner and pump are necessary to proportion the wetting agent and water at the desired ratio and to provide the moisture in sufficient quantity and at adequate pressure to meet the demands of the overall system.

Distribution is accomplished by spray headers fitted with pressure spray nozzles. Headers are used to apply the dust-suppressant mixture at each treatment point at the rate and spray configuration required to effect dust control.

Particulate emissions generated at plant process facilities (crushers, screens, conveyor transfer points, and bins) may also be controlled by capturing and exhausting emissions to a dry collection device. Depending on the physical layout of the plant, emission sources may be manifolded to a single centrally located collector or to a number of strategically placed units. Collection systems consist of an exhaust system with hoods and enclosures to confine and capture emissions and ducting and fans

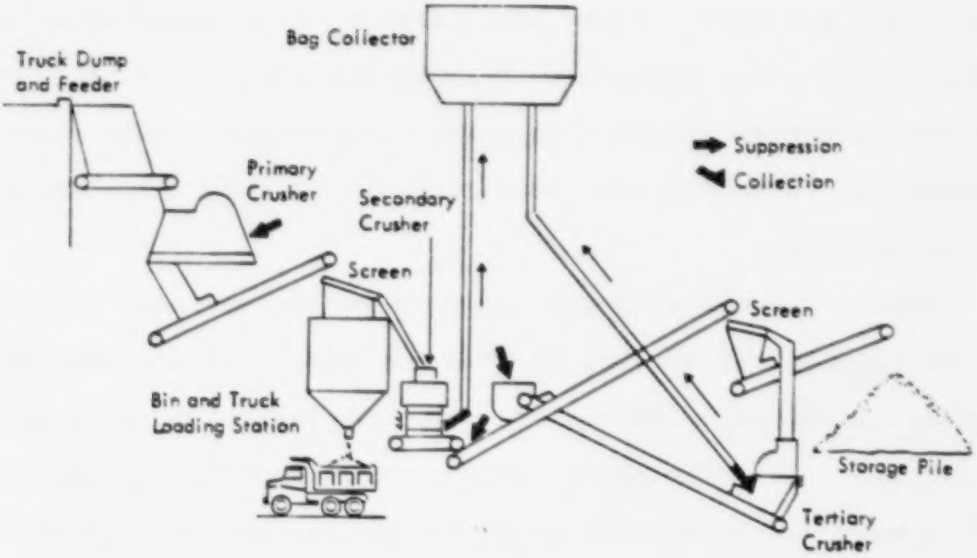

Bag Collector
Truck Dump and Feeder
Suppression
Collection
Primary Crusher
Secondary Crusher
Screen
Screen
Bin and Truck Loading Station
Storage Pile
Tertiary Crusher

Figure 2-8. Wet dust-suppression systems.[5]

to convey the captured emissions to a collection device where particulates are removed from the air stream before it is exhausted to the atmosphere.

The most commonly used dust-collection device in the crushed stone industry is the fabric filter (or baghouse). In most crushing plant applications, mechanical-shaker collectors (which require periodic shutdown for cleaning after 4 or 5 hours of operation) are used. These units are normally equipped with cotton sateen bags and operated at an A/C ratio of 2 or 3 to 1. A cleaning cycle, normally actuated automatically when the exhaust fan is turned off, usually requires only 2 or 3 minutes of bag shaking.

Fabric filters with continuous cleaning are used where it may be impractical to turn off the collector. Compartmented mechanical-shaker units may be used, but jet-pulse units are preferred. Jet-pulse units normally have wool or synthetic felted bags as the filtering medium and can be operated at a higher filtering ratio (as high as 6 or 10:1). Greater than 99 percent efficiency can be attained with either type fabric filter, even on submicron particle sizes. Outlet grain loadings recorded during EPA emission tests at several crushed stone facilities processing various kinds of rock seldom exceeded 0.01 gr/dscf.[5]

Other collection devices reportedly used in the industry include cyclones and low-energy scrubbers. Although these collectors may provide high efficiencies (95 to 99%) on coarse particles (40 μm and larger), their efficiencies are poor (less than 85%) on medium and fine particles (20 μm and smaller).[5] Although high-energy scrubbers and electrostatic precipitators could conceivably achieve results similar to those of a fabric filter, these methods are not currently used in the industry.

Dust control at portable crushed stone plants is considered by some industry spokesmen to be extremely difficult; however, the successful application of a wet dust-suppression system has been reported.[5] Furthermore, trailer-mounted, portable baghouse units are commercially available and have been used to control emissions from portable asphalt concrete batch plants. Although application of dry collection systems at portable crushed stone plants is not widespread, portable plant equipment manufacturers have indicated unofficially that this control option is indeed feasible and that the required hoods, enclosures, and ductwork could be integrated into the design of portable plant components. At least one manufacturer has drafted a proposal for such an installation.[5]

Drilling--

The two control methods available for controlling particulate emissions from drilling operations are water injection and aspiration to a control device.

Water injection is a wet drilling technique in which water or water plus a wetting agent or surfactant, usually a liquid detergent, is injected into the compressed air stream used to flush the drill cuttings from the hole. The injection of the fluid into the air stream produces a mist, which dampens the stone particles and causes them to agglomerate. As the particles are blown from the hole, they drop as damp pellets at the drill collar rather than becoming airborne.

Dry collection systems can also be used to control emissions from the drilling process. A shroud or hood encircles the drill rod at the hole collar. Emissions are captured under vacuum and vented through a flexible duct to a control device for collection. The device is often mounted on the drilling rig. Various devices are available, and their efficiencies vary. Cyclones or fabric filters preceded by a settling chamber are the most common. Air volumes required for effective control range from 500 to 1500 cfm, depending on the kind of rock, the hole size, and the penetration rate.

Crushing--

Wet suppression techniques are currently used on most crushers, with the exception of limestone crushers. Application of treated water at the feed point of the crusher has been proven effective in minimizing particulate emissions.

When dry collection systems are used, the upper portion of the crusher should be enclosed as completely as possible and exhausted according to the criterion established for transfer points. The crusher discharge/transfer belt interface also should be totally enclosed. An example of this type of system is shown in Figure 2-9. The exhaust rate will vary considerably with the type of crusher. Exhaust volumes from impact crushers or hammermills range from 4000 to 8000 cfm, whereas an exhaust

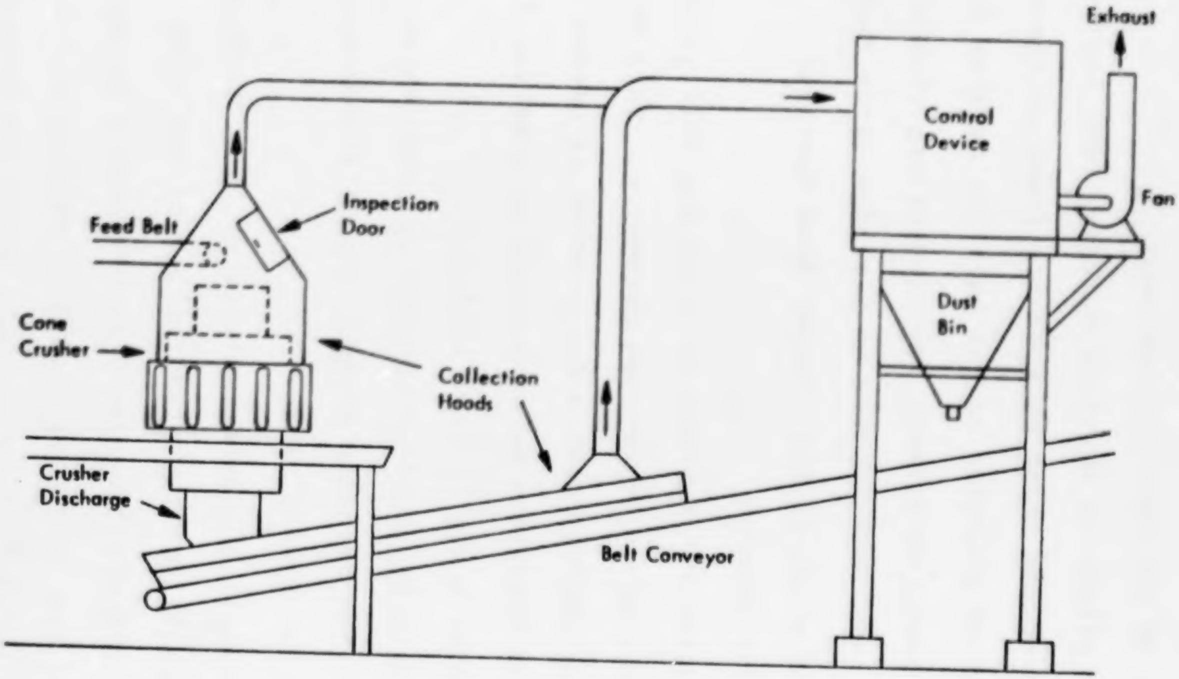

Exhaust
Control Device
Fan
Inspection Door
Feed Belt
Dust Bin
Cone Crusher
Collection Hoods
Crusher Discharge
Belt Conveyor

Figure 2-9. Hood configuration used to control a cone crusher.

rate of 500 cfm/ft of discharge opening should be sufficient on compression-type crushers. In either case, pickup should be applied downstream of the crusher at a distance at least 3.5 times the width of the receiving conveyor.[5]

To achieve effective emission control, ventilation should be applied both at the upper portion (or feed) of the crusher and at the point of transfer to the belt (or crusher discharge). This would not apply to primary jaw or gyratory crushers because operators must have ready access to dislodge large rocks that sometimes become stuck in the crusher feed opening.

Conveyor Transfer Points--

Water spraying effectively controls the dust generated by transferring crushed stone between conveyors. This method cannot be used, however, when a dry product is needed at the next step of the operation or when there is a market for the fines collected by a dry control system.

The alternative method of control is complete enclosure of the conveyor or the transfer point. Complete enclosure of both is impractical and rarely used.

At belt-to-belt conveyor transfer points, hoods should be designed to enclose both the head pulley of the upper belt and the tail pulley of the lower belt as completely as possible. By careful design, the open area should be reduced to about 0.5 ft^2/ft of belt width.[6] Conveyor belt speed and free-fall distance are factors that affect the air volume to be exhausted.

Screening--

Water sprays are used in most operations where wet or damp stone can be tolerated in the rest of the process. Water spray bars or nozzles are normally located at the discharge point of the conveyor, on the screen itself, and at the discharge points of the screen. This method has the following disadvantages: wet dust may bind on small screens, the water may retard later processes or prevent the stone from meeting specifications if the dust is not washed off. The use of washing plants will overcome most of these disadvantages.

Effective dry control at screening operations normally requires the use of several exhaust points. A full-coverage hood is often used to control emissions generated at screening surfaces. Additional or alternative ventilation air may be required at the screen feed and discharge ends. Exhaust volume requirements vary with the surface area of the screen and the amount of open area around the periphery of the enclosure. A well-designed enclosure will have a space of no more than 2 to 4 in. around the periphery of the screen.

Storage Bins--

Belt- or chute-to-bin transfer points differ from other transfer points in that there is no open area downstream of the transfer point. Hence, emissions are emitted only at the loading point. The ventilation point is normally located at some point remote from the loading point and exhausted at a minimum rate of 200 cfm/ft^2 of open area. Small fabric filter collectors (2000 to 6000 acfm) are then used to clean the dust-laden exhaust stream. The fabric filter may also be used to collect dust emitted from loadout operations beneath the storage bins. Snorkel hoods, which consist of an annular space around the opening of the discharge chutes, are an effective means of minimizing particulate emissions that occur as trucks are being loaded with stone product.

2.2 EVALUATION OF VARIOUS CONTROL ALTERNATIVES

A number of factors that must be weighed in selection of a control device for a specific process and plant are given in Table 2-5.

In terms of the technical competitiveness of the various control devices under consideration, the processes often dictate the selection of the control device. For example when the revised kraft pulp mill emission standards are implemented, it may become necessary to develop hybrid systems either extending the capability of the existing unit or adding other generic control devices. Especially with regard to bark boilers, the historical use of mechanical collectors alone will no longer be adequate to meet proposed regulations. Increasing efficiency requirements may cause a shift in the selection of control devices as well as a move to industrial energy conservation.

2.3 ELECTROSTATIC PRECIPITATORS

2.3.1 System Design Parameters

This section deals with the major parameters that must be weighed in design of an electrostatic precipitator. The process applications under consideration are recovery furnaces and

Table 2-5. FACTORS BEARING ON CONTROL DEVICE SELECTION

Characteristics of particles and gas stream	Facilities, costs, legal factors
Particles Electrical properties (precipitators only) Resistivity Dielectric constant Physical properties Surface properties abrasiveness porosity Density Shape Hygroscopic nature Adhesivity Cohesivity Particulate concentration Size distribution Gas stream Flow rate Process Viscosity Chemical composition Acid constituents Alkaline constituents Sulfur oxide content Moisture content	Plant facility Waste treatment Space restriction Product recovery Water availability Cost of control Engineering studies Hardware Auxiliary equipment Land Structures Installation Start-up Power Waste disposal or recycle Water Materials Gas conditioning Labor Maintenance Taxes Interest on borrowed capital Depreciation Insurance Return on investment Regulations Maximum particulate and SO_2 emission rates allowed by Federal, state, and local laws

bark/fossil-fuel boilers in the kraft pulp mill industry. The dust emitted includes sodium sulfate, sodium carbonate, and sodium chloride from recovery furnaces and carbon (char), sand, and fly ash from bark/fossil-fuel boilers.

These industrial applications are essentially all retrofit pollution control systems (and therefore site-specific). Variation in processes can cause wide differences in expected performance.

The design procedure is straightforward; given certain input variables (process application, process flow correlations and parameters, and applicable particulate emission standard) and applying experience and theory, one can develop a design that meets the criteria for efficiency and cost. This format is illustrated in Table 2-6.

Table 2-6. PARAMETERS AFFECTING PRECIPITATOR DESIGN

System input	Basic design parameters	Specific design parameters	System output
Process application Process conditions Applicable emission standard	Total acfm Total collection area Power density	Gas and dust characteristics Precipitator capacity Electrical/ mechanical Electrical energization System performance	Overall and fractional mass collection efficiency Capital investment Annual cost

Basic Design Parameters--

The objective here is to determine from the process application, process conditions, and applicable emission regulations the values for gas volumetric throughput (acfm), total plate collection area (ft^2), and power density (watts/ft^2 of collecting surface). These three parameters form the basis for precipitator design.

The total gas volume is dictated by process and production level. Knowing the total acfm and the specific collection area (SCA, ft^2/1000 acfm), one can determine the total area required to comply with an emission regulation. The equations for doing so are given below.

$$SCA = \frac{16.67 \ln^{1/b} (1-\bar{\eta})}{w_k} \qquad \text{(Eq. 1)}$$

$$\bar{\eta} = (1 - \frac{C_o}{C_i})$$

where

$\bar{\eta}$ = Overall mass collection efficiency, percent

b = Slope of line (reference line slope = 0.5)

w_k = Modified migration velocity, ft/sec

C_o = Allowable outlet grain loading, gr/dscf*

C_i = Inlet grain loading, gr/dscf*

The proposed Federal standard for new recovery furnaces is 0.10 g/dscm**[7] of saltcake emissions and is equivalent to 0.04 gr/dscf. Based on a typical inlet concentration of 3.8 gr/scf[1] for a conventional recovery furnace, this corresponds to a required control efficiency of 98.95 percent. Where codes are based on pounds of particulate emitted per air-dried ton of pulp, the 0.04 standard may not be stringent enough for high product processing levels.

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* dscf = dry standard cubic foot.

** dscm = dry standard cubic meter.

The presence of fines, although representing a small weight fraction, may cause a visible plume. Where "equivalent opacity" is used as a standard, a visible plume may not be acceptable.

The following excerpt from rules and regulations for kraft pulp mill applications in the Federal Register illustrates proposed standards.[8]

> "The proposed standards would limit emissions of particulate matter from three affected facilities at kraft pulp mills. The limits are (1) 0.10 gram per dry standard cubic meter (g/dscm) for recovery furnaces, (2) 0.15 gram per kilogram of air-dried pulp (g/Kg ADP) for smelt dissolving tanks, (3) 0.15 g/dscm for lime kilns when burning natural gas and (4) 0.30 g/dscm for lime kiln when burning oil. Visible emissions from recovery furnaces would be limited to 35 percent opacity."

Migration velocity--The modified migration velocity is a function of electrical energization of the precipitator and of gas properties. It is often conveniently linked with resistivity level. A representative range of migration velocity in the pulp and paper industry is 0.21 to 0.31 ft/sec. Because of the variation in the ash resistivity due to cyclic operation of the pulping cycle a precipitator designed for recovery furnaces may have an uncertainty of approximately 15 to 20 percent in precipitator migration velocity. For example, in a precipitator designed for 98 percent collection efficiency, the measured efficiency could vary from 97 to 98.40 percent.[9] A typical migration velocity range in bark/fossil-fuel boiler applications is 0.2 to 0.5 ft/sec.

A digression is in order at this point to clarify the usage of w_k (modified migration velocity) in contrast to the effective migration velocity w, which is used in the conventional Deutsch-Anderson efficiency equation. The effective migration velocity, w, is a function of several factors, including precipitator length, overall mass collection efficiency, and gas velocity. The variation in w within a given precipitator is caused by changing particle size distribution as precipitation proceeds in the direction of gas flow.

The modified migration velocity, w_k, as presented by Matts and Öhnfeldt[10] can be treated essentially as a constant for any application. It is, of course, strongly dependent upon the inlet particle size distribution.

Power input--The third basic design parameter is power density required to establish the optimum voltage-current characteristics of the corona, given the dust entering the precipitator. Power density is a function of electrical resistivity, particle size characteristics and distribution, gas loading and composition, gas temperature, and gas pressure. It is often conveniently linked with resistivity, such that for a moderate resistivity of 10^9 ohm-cm the value will be approximately 2.5 watts/ft^2. For recovery furnaces a typical range of power input is 1.1 to 1.5 watts/ft^2, as calculated from field operating data. For bark boilers a range of power input is 1 to 3 watts/ft^2.

Table 2-7 illustrates a general correlation between power density and dust resistivity, based on typical values for fly ash.

Table 2-7. DESIGN POWER DENSITY

Resistivity, ohm-cm	Watts/ft^2 of collecting plate
10^{4-7}	4.0
10^{7-8}	3.0
10^{9-10}	2.5
10^{11}	2.0
10^{12}	1.5
$>10^{13}$	<1.0

Operating voltages from field data can range from 45 to 55 kV for 9-inch plate spacing. Current densities, also from field data, range from 0.02 to 0.05 mA/ft^2 for recovery furnace applications. Field voltages and current densities for bark boilers range from 40 to 45 kV and 0.02 to 0.06 mA/ft^2, respectively. These values are not constant for each point in the precipitator. At the inlet section where the dust loading is greatest, the voltage-current characteristics will be significantly different from those at the outlet.

It appears that resistivity plays a significant role in selection of w_k and power density, yet there is no precise or universally applied method for predicting resistivity from the material entering the furnace or process and the process conditions.

Specific Design Parameters--

Table 2-8 is a compilation of design parameters and input variables grouped in logical categories.

Precipitator Size--One of the first structural parameters

Table 2-8. DESIGN PARAMETERS AND DESIGN CATEGORIES FOR ELECTROSTATIC PRECIPITATORS

Dust composition[11]

- Na_2SO_4
- Na_2CO_3
- NaCl
- C (Char)
- Sand
- Fly ash

Precipitator capacity

- No. precipitators
- No. chambers (units)/precipitator
- No. ducts/chamber (unit)
- Duct spacing
- Plate height
- Treatment length
- Section lengths and total no. of each (per precipitator)
- Collecting area
- No. electrical sections parallel to gas flow (per precipitator)
- No. electrical sections across gas flow (per precipitator)
- No. hoppers parallel to gas flow (per precipitator)
- No. hoppers across gas flow (per precipitator)

Rapping, electrodes, etc.

- Type discharge electrode
- Length discharge electrode/vibrator or rapper
- Type discharge electrode/vibrator or rapper
- Type collecting electrode
- Area collecting electrode/rapper
- Type collecting electrode rapper

Table 2-8 (continued)

Electrical energization (of each electrical section)

- Power density
- Length of collecting electrode/T-R
- Mode (switching)
- Corona power
- Current density
- Current/T-R set

Performance-related parameters

- Gas flow
- Gas temperature
- Gas (treatment) velocity
- SCA
- Overall mass collection efficiency
- Fractional mass collection efficiency
- Inlet grain loading
- Outlet grain loading

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to be determined is the width of the precipitator(s). This value is dependent on the total number of ducts as determined from Equation 1.

$$\text{Total no. ducts} = \frac{\text{acfm}}{(\text{T.V.})(60)(\text{P.S.})(\text{P.H.})} \qquad \text{(Eq. 2)}$$

where

acfm = total gas volumetric throughput, acfm

T.V. = gas (treatment) velocity, ft/s

P.S. = plate spacing, ft

P.H. = plate height, ft

A practical approach from the standpoint of energization and reliability is to limit the total number of ducts per chamber. The number of chambers is determined by the total number of ducts, which is determined from Equation 2 and the associated criteria. The total number of precipitators needed will depend on the degree of reliability required, space limitations at the plant site, and the relative ease with which the effluent gas can be distributed to the precipitator(s).

The second general design equation provides a guide to the length of the precipitator, which is dependent on treatment velocity, plate spacing, plate height, gas volumetric throughput, and total collecting surface. (Eq. 3)

$$\text{Treatment length} = \frac{\text{Total collection surface}}{(\text{No. pptrs.})(\text{No. chambers/pptr.})(\text{No. ducts/chamber})(\text{P.H.})(2)}$$

The design treatment length will be determined by selection of an integer value of standard section (field) lengths that may be offered by the precipitator manufacturer. If it is found, for example, that four fields are required, two of one length and two of another, structural considerations such as hopper spans may determine the positioning of the fields in the direction of gas flow.

Mechanical sections result from the chamber-wise and field-wise sectionalization of an electrostatic precipitator. Hopper selection is based on the size of the mechanical sections and the predicted inlet grain loading.

Treatment velocity (T.V.) is a function of dust resistivity. In recovery furnace applications, the precipitator treatment velocity ranges from 2 to 5 ft/s; in bark/fossil-fuel boiler applications the range is 3.2 to 4.5 ft/s. The lower velocity should be considered when burning salt-water-soaked bark material. In general, the less resistive the dust, the shorter can be the treatment time.

Plate spacing is more or less fixed by the precipitator manufacturer, depending on his experience with the various process applications and conditions, predicted velocity distribution across the precipitator, and type of plate. Plate spacing usually ranges from 9 to 12 inches.

In selecting plate height, the designer attempts to maintain both the required treatment velocity and an adequate aspect ratio. The aspect ratio is defined as the ratio of the length of a precipitator to its height. Historical data indicate that it can vary from 0.75 to 1.5. The practical limitations on plate height imposed by structural stability requirements are obvious. Each manufacturer limits the practical plate heights in accordance with the overall design.

The total number of ducts dictates the width of the precipitator. The designer next requires some indication of the system sectionalization, as indicated in Figure 2-10. Chamberwise (parallel) sectionalization is sectionalization across the gas flow, whereas series sectionalization is in the direction of gas flow.

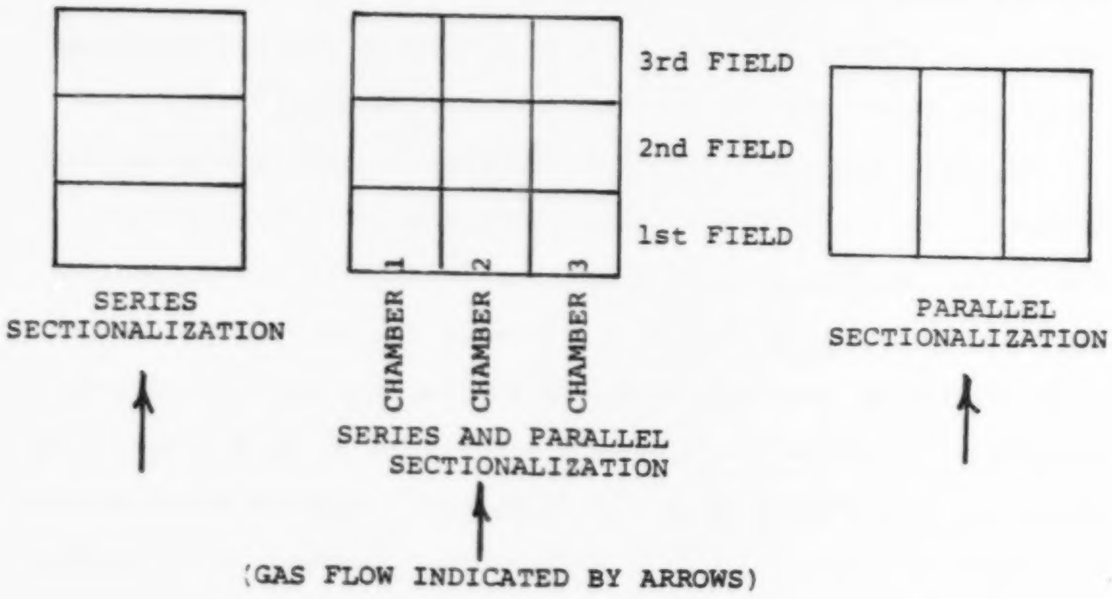

3rd FIELD
2nd FIELD
1st FIELD
SERIES SECTIONALIZATION
CHAMBER 1
CHAMBER 2
CHAMBER 3
SERIES AND PARALLEL SECTIONALIZATION
PARALLEL SECTIONALIZATION
(GAS FLOW INDICATED BY ARROWS)

Figure 2-10. Sectionalization of a precipitator.

Discharge/collection electrodes--The geometry of the discharge electrode (fine, barbed, rigid, etc.) will determine corona current-voltage characteristics. The smaller the wire or the more pointed its surface, the greater the value of corona current for a given voltage. Very fine or exotic wires, however, may have potential for breakage and possible dulling of spiked points with time.

The maximum value for length of standard 0.109-in.-diameter discharge wire per vibrator is 3000 ft in recovery furnace precipitators and 3500 ft in bark boilers. The area of collecting surface per vibrator or rapper usually ranges from 2000 to 2500 ft^2 in bark boiler precipitators.

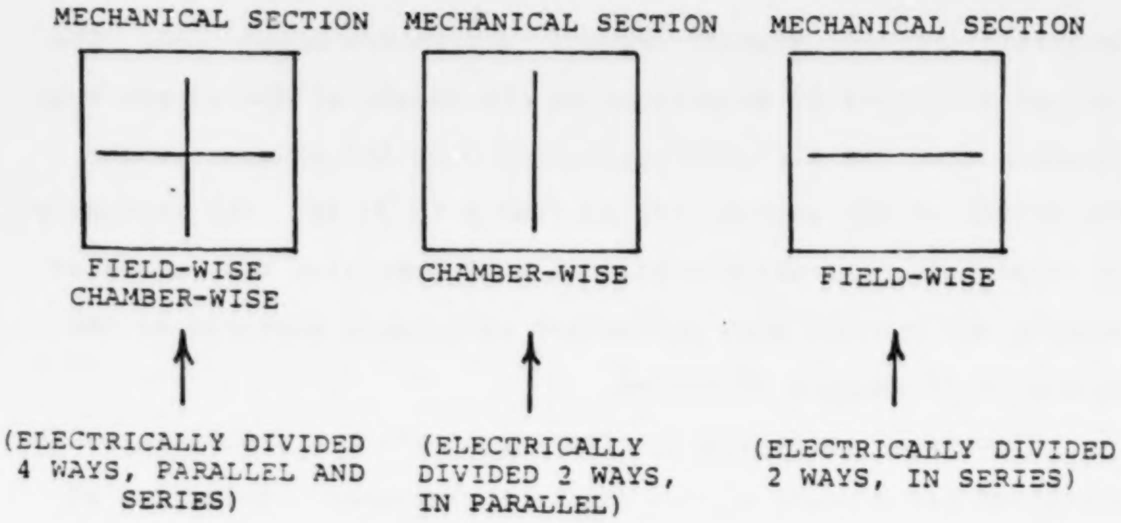
Baffles are used to provide stiffness for support of the collecting plate and a region of low turbulence to minimize reentrainment of dust, particularly during rapping. Although a variety of plates are commercially available, their functional characteristics are not substantially different.[12]

Vibrators/rappers--The air vibrator imparts energy at high frequency to the discharge electrodes and collecting plates. The system is designed to create a vibration in the collecting plates and discharge electrode wires to dislodge accumulations of particles so that the plates and wires are kept in optimum operating condition. A pressure setting of 35 to 40 psi on the pneumatic vibrator is generally adequate. Rappers are occasionally used on kraft pulp mill applications instead of vibrators for cleaning wires.

Rappers can be pneumatic or electromagnetic. Single-impact (magnetic-impulse, gravity-impact) rappers are often used. The rapping intensity is determined by the height of the rapper when released from its elevated position and by the plunger weight. The weight of the plunger may be from 8 to 32 lb. The frequency of rapping is determined empirically by observing the values of opacity and overall mass collection efficiency measured as the intensity of rapping is varied.

Electrical energization--The way in which a precipitator is energized has a great effect on its performance. Selection of the energization system is probably as site-specific as it is process-specific. The chief considerations in both utility and industrial applications are number and size of T-R sets, the number of electrical sections, degree of high-tension sectionalization, half wave - full wave (HW-FW) operation, and changes in voltage-current characteristics as precipitation proceeds in the direction of gas flow.

A mechanical section by definition may become an electrical section (bus section) if it can be separately energized. Within an electrical section one may have a chamber-wise or field-wise high tension split or both (see Figure 2-11). The advantage of splitting a mechanical section both chamber-wise and field-wise is increased reliability with, of course, increased cost. For the applications under consideration, both inlet and outlet sections are often split in the direction of gas flow. In this configuration the effects of variations in temperature and dust


MECHANICAL SECTION
MECHANICAL SECTION
MECHANICAL SECTION
FIELD-WISE
CHAMBER-WISE
CHAMBER-WISE
FIELD-WISE
(ELECTRICALLY DIVIDED 4 WAYS, PARALLEL AND SERIES)
(ELECTRICALLY DIVIDED 2 WAYS, IN PARALLEL)
(ELECTRICALLY DIVIDED 2 WAYS, IN SERIES)

(DIRECTION OF GAS FLOW INDICATED BY ARROWS)

Figure 2-11. High tension splits.

loading across the chamber because of poor flow characteristics in ductwork leading to these retrofit units are minimized. Reliability is increased at the inlet, which is often in the half-wave mode. If one bus section fails, a jumper cable can be engaged to apply full wave to the "companion" bus section and thereby prevent that bus section from failing.

Reliability relates not only to sectionalization of a given collection area but also to the addition of collection area or electrical fields. The degree of reliability can be defined in terms of redundant capacity, which is a function of anticipated failure and time between maintenance periods. Redundancy may be defined as that additional area in a precipitator that compensates for the "normal" level of unavailable collecting area. To achieve a reliable yet cost-competitive design, one must have detailed information on dust characteristics and a clear understanding of the effect of process variations on precipitator performance.

The basic consideration in energizing the precipitator is to maximize the power input to achieve the highest collection efficiency from a given collection area. The decision on the degree of sectionalization, however, is made quite independently of the way in which the precipitator is to be energized. The number, size, and mode of operation (HW or FW) of the T-R sets can be manipulated to provide the required current density within each bus section of the precipitator. The size of the transformer rectifer (TR) sets is selected to provide lower current density at the inlet.

In spark-limited operation, half-wave allows time during the off-half cycle for recovery from the sparking condition (spark quenching). Complete decay of the charging field and of collection efficiency during the off-half cycle is avoided because of the capacitive effect of high-resistivity dust, which tends to maintain the field potential.

In cases where the resistivity of the dust has been reduced, i.e., because of in creased temperature of operation or high carryover of carbon the capacitative effect of the dust is also reduced. Thus, the charging field decays move in half wave then full wave.

The selection as to the mode of operation is site-specific, and the variability of performance measurements in full-scale precipitators may overwhelm any differences due to operation in either mode. In the processes under consideration, half-wave has been often used in the inlet fields and full-wave in the outlet fields.

In summary, precipitator sectionalization and energization are based on maximizing the power input to the precipitator to achieve the highest efficiency from a given collection area while minimizing the potential for poor performance as a result of various failure patterns. The reliability of precipitator performance is a function of process flow conditions and dust characteristics, reliability requirements, and the designer's experience. The way in which a precipitator is energized depends on the sectionalization configuration and the current density to be supplied to each bus section, as determined by chemical and physical characteristics of the dust, dust loading, and the gas stream. The number, size, and mode of operation of the T-R sets can be fitted to the sectionalized configuration after bus section design has been established.

2.3.2 Correlations

The foregoing discussion of precipitator design shows that three parameters are of central interest: gas volumetric throughput (acfm); total collecting area (ft^2); and power density (watts/ft^2 of collecting surface). The graphical correlations discussed in this section relate these basic design variables to process application. The designer's judgment, experience, and understanding of precipitator theory allow him to select the values of overall mass collection efficiency, SCA, and power density required for given process conditions and emission standards. A word of caution is needed, however. It is not intended that the approach presented here should be directly applied to a specific site or installation. In such applications a number of very practical points must be considered, such as design features to control and minimize large-scale turbulence, gas sneakage, and particle reentrainment in the precipitator.

The following discussion will examine some design trends that have been established for precipitator sizing in the kraft pulp mill industry. The following processes are discussed:

1) Conventional recovery furnaces
2) Low-odor recovery furnaces
3) Bark/fossil-fuel boilers.

ESP Design Correlations - Conventional Recovery Furnaces--

The basic pulping process is described in Section 2.1.1. In this section the effect of the various process parameters affecting the performance of the electrostatic precipitators is examined more closely. For this purpose the important process parameters are summarized in Table 2-9.

Table 2-9. TYPICAL OPERATING CONDITIONS FOR PRECIPITATORS ON CONVENTIONAL RECOVERY FURNACES

Particle size distribution	$\bar{x}$- = 1.4 → 1.9 μm σ = 3.0 → 2.04
Grain loading	3 - 5 (gr/acf)
Particle material Sp. Gr. (75% Na_2SO_4)	2 - 2.5
Gas temperature	280 - 325 °F
Particle resistivity	10^8 - 10^{10} ohm-cm
Moisture content	20 - 30% by volume

Modified Deutsch Model--Matts and Öhnfeldt[10] proposed an empirical modification of the classical Deutsch equation[13] that essentially removes the size dependence from w, the particle migration velocity. Their equation is: $\bar{\eta} = 1 - \exp(-w_k A/Q)^k$ where k is said to be equal to 0.5 in most cases. It can be shown, however, that w_k is dependent on the inlet particle size distribution,[14] which changes with each application even if all other characteristics of the precipitator are the same.

Feldman[14] proposed another efficiency equation of the form

$$\bar{\eta}- = 1-C^{(w'A/Q)^m} \qquad \text{(Eq. 4)}$$

Equation 4 has an advantage of separating all the effects of size distribution into the constants C and m and of defining w', which is dependent only on the electrical energization of the precipitator and gas properties. It should be noted that equation 4 is still based on the Deutsch model and is subject to its assumptions and limitations. The advantages over the Deutsch equation are that the "effective migration velocity" is replaced by a quantity w' which depends on the electrical and gas properties and that the two constants C and m in equation 4 account for the size distribution effects. In the absence of abundant design data, this equation was used to generate theoretical design lines for precipitators on kraft recovery furnaces and bark/fossil fuel fired boilers. This equation has been confirmed in part by available test data. The derivation of equation 4 is discussed briefly in the following paragraphs.

The electrical force on a charged particle in an electric field is given by:

$$F = qE_p \qquad \text{(Eq. 5)}$$

where E_p (from the Deutsch model) is the electric field strength at the precipitator collecting electrode. (See Table 2-10. Units are in the mks system.) The force opposing particle motion through the gas is:

$$F = 3\pi\mu\, dw_d/CI \qquad \text{(Eq. 6)}$$

Equating forces and solving for the migration velocity of particles of size d:

$$w_d = \frac{qE_pCI}{3\pi\mu\ d} \qquad \text{(Eq. 7)}$$

CI is the Cunningham correction factor given by:

$$CI = 1 + 2.5\lambda/d + 0.84\lambda/d \exp(-.435/\lambda) \qquad \text{(Eq. 8)}$$

The particle charge q can be represented by the Cochet equation:

$$q = [(1 + \frac{2\lambda'}{d})^2 + \frac{2}{(1 + 2\lambda'/d)}] (\frac{Kr-1}{Kr+2})]\pi d^2 \varepsilon_o E_o \qquad \text{(Eq. 9)}$$

Table 2-10. NOMENCLATURE FOR THE ELECTROSTATIC PRECIPITATOR COMPUTER MODEL

A = precipitator collecting area

a = particle-size-dependent parameter, Eq. (11)

C = constant defined in Eq. (19)

CI = Cunningham's slip correction, Eq. (8)

d = particle diamter

E_o = peak charging field

E_p = electric field near the collecting electrode

F = Stoke's drag force on the particle

$f_1(d)$ = inlet particle size distribution function

$g(d)$ = particle size dependent parameter, Eq. (14)

Kr = particle relative dielectric constant

k = constant defined in Eq. (13)

m = constant defined in Eq. (19)

n = number of mechanical sections

Q = volumetric gas flow rate

q = particle charge magnitude

r = particle fraction assumed reentrained at every mechanical section

SCA = specfic collection area

SCA_C = specific collection area of precipitator on conventional recovery furnace

SCA_L = specific collection area of precipitator on low odor recovery furnace

w = migration velocity

w_d = migration velocity of a particle of size d

w_k = overall effective migration velocity

(continued)

Table 2-10 (continued)

w' = modified migration velocity defined in Eq. (22)

w'_C = modified migration velocity on conventional recovery furnace application

w'_L = modified migration velocity on low odor recovery furnace application

$\bar{x}$ = mass mean diameter

ε_o = permittivity of free space

η_d = collection efficiency of particle size d also efficiency correct for reentrainment loss r on particle size d

η'_d = collection efficiency on particle size d without reentrainment

η_T = overall collection efficiency of size d, Eq. (35)

λ = mean free path of gas molecules

λ' = empirical mean free path in Eq. (9)

μ = dynamic gas viscosity

σ = geometric standard deviation of the particle size distribution

Π = product

where

Kr = relative dielectric constant of the particle

and

λ' = empirical mean free path

= 0.1 μm at 20°C and 1 atm. pressure

The Cochet equation accounts for particle charging by both field charging and diffusion charging mechanisms. This is important in analyzing the effects of particle size, since the charging mechanism changes from field charging to diffusion charging in the submicron range. Although there are more accurate methods of computing particle charge than the Cochet equation, these require numerical solution. For the purposes of this discussion, the Cochet equation is entirely adequate in representing the effect of particle size on charge.

Combining equations 7 and 9 and defining

$$a = [(1 + \frac{2\lambda'}{d})^2 + \frac{2}{(1 + 2\lambda'/d)} (\frac{Kr - 1}{r + 2})], \qquad \text{(Eq. 10)}$$

the particle migration velocity for particles of size d becomes:

$$w_d = (\frac{\varepsilon_o E_o E_p}{3\mu}) \text{ aCId} \qquad \text{(Eq. 11)}$$

For particles of a single size, d, the Deutsch equation can be applied to calculate efficiency:

$$(1 - \eta_d) = \exp[\frac{-w_d A}{Q}] = \exp [-(\frac{\varepsilon_o E_o E_p A}{3\mu Q}) \text{ aCId}] \qquad \text{(Eq. 12)}$$

Defining new terms:

$$k \equiv \frac{\varepsilon_o E_o E_p A}{3\mu Q} \qquad \text{(Eq. 13)}$$

$$g(d) \equiv \text{aCId} \qquad \text{(Eq. 14)}$$

The single-size efficiency equation becomes:

$$(1 - \eta_d) = \exp[-kg(d)] \quad \text{(Eq. 15)}$$

The overall collection efficiency is found by integrating over the inlet size distribution, f_1 (d):

$$(1 - \bar{\eta}) = \int_0^{\infty} (1 - \eta_d)\, f_1\, (d)dd \quad \text{(Eq. 16)}$$

Assuming a log-normal inlet distribution this becomes:

$$(1 - \bar{\eta}) = \frac{1}{\sqrt{2\pi}\,\ln\sigma} \int_0^{\infty} \exp[-kg(d)-0.5(\frac{\ln d/\bar{x}}{\ln\sigma})^2]d\ln d \quad \text{(Eq. 17)}$$

If the integral in this equation could be evaluated directly, one would have the overall efficiency equation in terms of $\bar{x}$, σ, and k; i.e. size-dependent variables would be distinguished from the other variables. However, the integral must be evaluated numerically, and therefore no simple analytic expression for efficiency is obtained directly. It is possible to arrive indirectly at a simple efficiency equation through use of equation 17. The procedure is as follows.

Equation 17 is solved numerically on the computer to obtain different $\bar{\eta}$, k pairs for the typical inlet particle size distribution in a recovery furnace, $d \sim 1.7$ µm, and $\bar{x} = 2.5$. The results are plotted on log-log paper for $[-\ln(1-\bar{\eta})]$ versus k. As shown in Figure 2-12, this plotting yields a straight line, which indicates a direct relationship between $(1-\bar{\eta})$ and k. The equation of a straight line on this plot can be written as:

$$\ln\left[\frac{\ln(1-\bar{\eta})}{\ln(1-\bar{\eta}_o)}\right] = m\ln(k/k_o) \quad \text{(Eq. 18)}$$

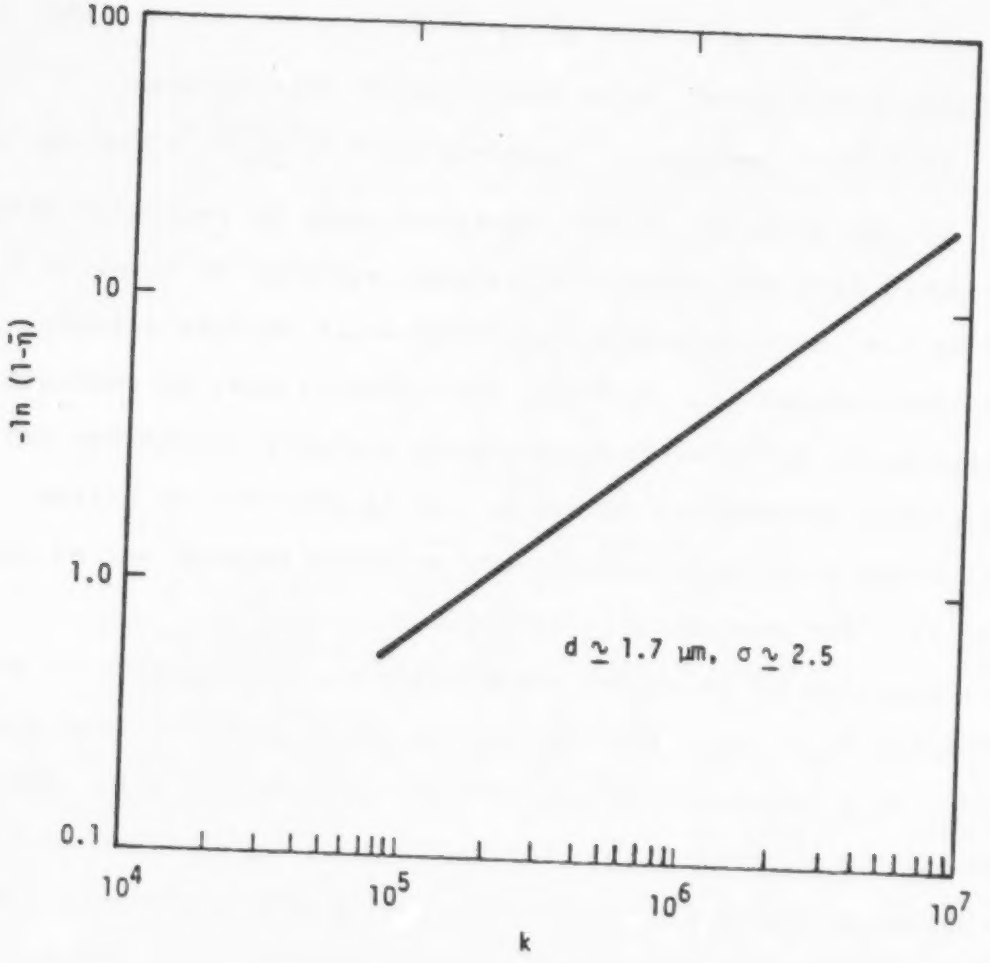


Figure 2-12. Plot of k versus -ln(1-$\bar{\eta}$) for recovery furnace applications.

If C is defined as a value of $(1-\bar{\eta}_o)$ when $k_o = 10^4$, equation (18) becomes:

$$\ln \left[\frac{\ln(1-\bar{\eta})}{\ln C}\right] = m \ln (10^{-4}k) \qquad \text{(Eq. 19)}$$

or

$$(1-\bar{\eta}) = C^{(10^{-4}k)^m} \qquad \text{(Eq. 20)}$$

By referring to equation (13), the term $10^{-4}k$ can be written as:

$$10^{-4}k = w' \frac{A}{Q} \qquad \text{(Eq. 21)}$$

where

$$w' = \frac{\varepsilon_o E_o E_p}{3\mu} \times 10^{-4} \qquad \text{(Eq. 22)}$$

Thus, the desired efficiency equation is:

$$1 - \bar{\eta} = C^{(w'A/Q)^m} \qquad \text{(Eq. 23)}$$

where w' is a modified migration velocity (its dimensions are $\sec^{-1}$) and is independent of the inlet particle size distribution but is completely dependent on the electrical energization of the precipitator.

Model application to conventional kraft pulp mills--To generate absolute numbers for overall efficiency and SCA, w' must be estimated. Available electrical data from field precipitators (see Table 2-11) can be used to determine w', as follows:

$$w' \equiv \frac{\varepsilon_o E_o E_p}{3\mu} \times 10^{-4} \quad (\sec^{-1})$$

where E_o is the peak charging field and E_p is the average electric field near the collecting plate commonly known as the collecting field. Estimates of E_o could be made knowing the secondary voltage wave form to the precipitator and the absolute magnitude of the average secondary voltage at the discharge electrode. Generally full-wave rectifiers are used on kraft pulp mill precipitators and the secondary average operating voltage is on the order of 48 kV. This results in

$$E_o \doteq \frac{48 \times 10^3 \times 2}{0.1143} \qquad \text{(Eq. 24)}$$

$$E_o = 5.95 \times 10^5 \ \text{(v/m)} \qquad \text{(Eq. 25)}$$

Table 2-11. TYPICAL ELECTRICAL OPERATING DATA ON STANDARD 9-INCH PLATE PRECIPITATOR WITH 0.109-INCH DISCHARGE ELECTRODES

Avg. secondary voltage at the discharge electrode	45-55, kV avg
Avg. plate current density	10-50, mA/1000 ft^2
Avg. power density	1-2.5, W/ft^2

Analytical expressions to estimate the collecting electric field are relatively hard to derive in the case of wire-plate precipitators.[15] A simple expression for E_p can be derived for present purposes, assuming low current density.[16,17] Available field data on a 9-in. plate precipitator with 0.109-in. diameter discharge electrodes indicates that for this application, V_c is on the order of 23 kV average at 300°F. For a typical operating voltage of 48 kV average, it is estimated that E_p will be on the order of 4.5×10^5 (V/m). The dynamic gas viscosity (μ) at 300°F is theoretically estimated at

$$\mu = 2.5 \times 10^{-5} \ (\text{Nt-s/m}^2) \qquad \text{(Eq. 26)}$$

Thus, substituting the various quantities in equation 22 one obtains:

$$w' = \frac{8.854 \times 10^{-12} \times 5.95 \times 10^5 \times 4.5 \times 10^5}{3 \times 2.5 \times 10^{-5}} \times 10^{-4} \qquad \text{(Eq. 27)}$$

$$w' = 3.155 \ (s^{-1}) \qquad \text{(Eq. 28)}$$

Therefore, for the recovery furnaces on kraft pulp mills, the design equation becomes:

$$\frac{A}{Q} = \frac{1}{3.155} \ \frac{\ln \ (1-\bar{\eta})}{\ln C}^{1/m} \qquad \text{(Eq. 29)}$$

The inlet particle-size-dependent parameters C and m are determined by solving equation 17 numerically on the computer for the typical inlet particle size distribution of $d = 1.7 \ \mu m$ and $\sigma = 2.5$. The values of C and m are:

$C \approx 0.957; \ m \approx 0.89$

This design equation for precipitator size on the conventional kraft pulp process mill is given by:

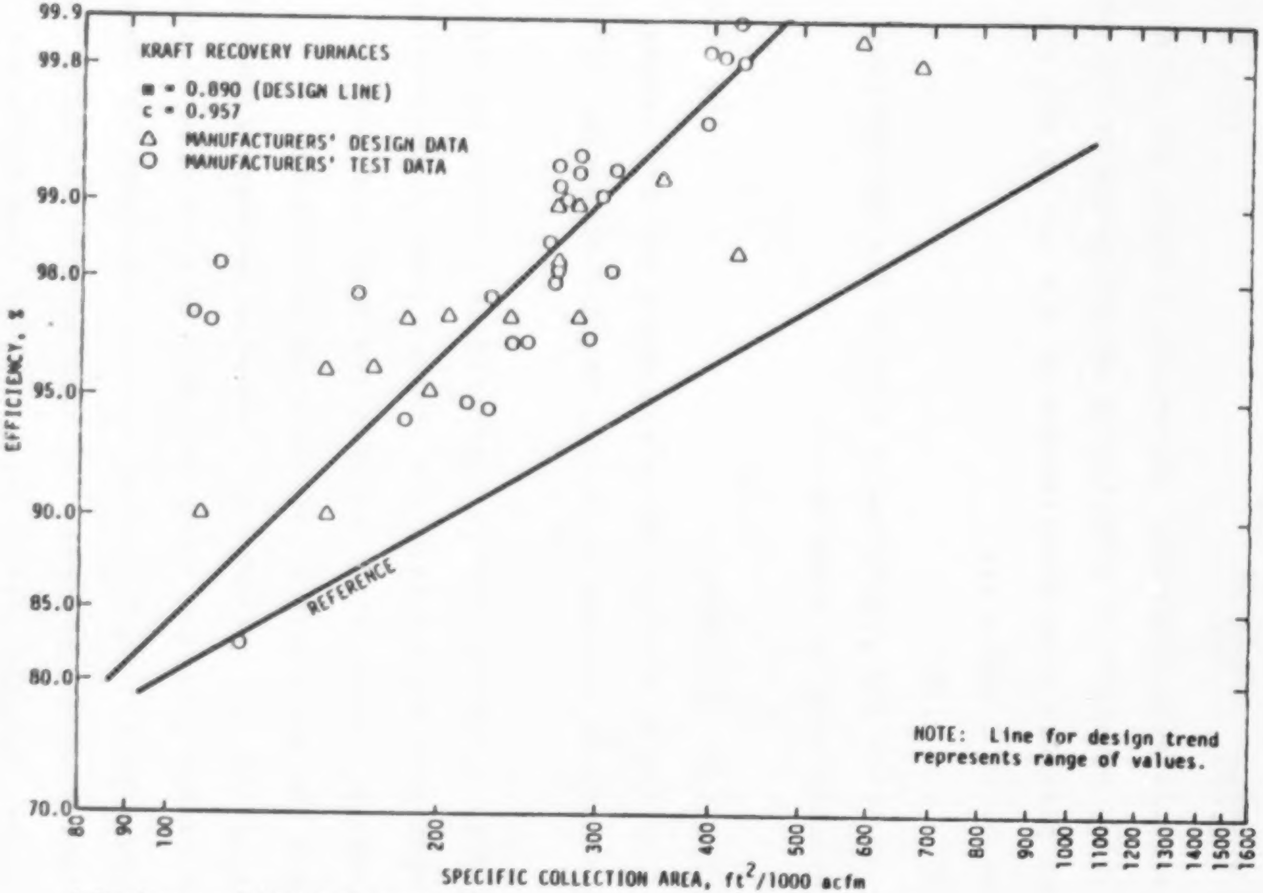
$$\frac{A}{Q} = \frac{1}{3.155} \ \frac{\ln(1-\bar{\eta})}{\ln(0.957)}^{1/0.89} \qquad \text{(Eq. 30)}$$

To convert from mks to English units the value for A/Q (sec/m) in equation 30 should be divided by 0.197, thereby obtaining $ft^2/1000$ acfm.

Figure 2-13 shows the design line predicted using equation 30 and the test data points from the various jobs on conventional recovery furnaces. Correlation between the predicted model efficiency and the performance test data is excellent.

Precipitator Design Correlations for Low-odor Recovery Furnaces--

Efforts of the pulp and paper industry to eliminate odorous gases escaping from pulp mills often involve switching to the so-called low-odor recovery process. In this process the odor levels are lower, but the particulates emitted have different



* Based on a modified Deutsch equation.

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Figure 2-13. Selected precipitator correlations* for conventional kraft pulp mill recovery furnaces.

physical properties. R.L. Bump[18] has summarized some important differences that must be accounted for in sizing a precipitator for a low-odor recovery furnace. The differences affecting precipitator performance are summarized in Table 2-12.

Table 2-12. DIFFERENCES IN PARTICULATE PROPERTIES IN CONVENTIONAL AND LOW-ODOR RECOVERY PROCESSES

Parameter	Conventional	Low-odor
Temperature, °F	280-325	340-450
Moisture content, %	20-30	7-20
Bulk density, lb/ft^3	20-25	5-10
Tenacity	Moderate	High
Sulfur content	Low	High

The dynamic gas viscosity plays an important role in determining particle drag force. Typical compositions[19] of flue gas entering the precipitator on a conventional recovery boiler (wet basis) and a low-odor recovery boiler are shown in Table 2-13. Assuming typical gas temperatures of 300°F and 400°F in conventional and low-odor applications and assuming 1 atmosphere absolute pressure, one can calculate the dynamic gas viscosities for the two applications. Calculation indicates that

$$\frac{\mu \text{ low-odor}}{\mu \text{ conventional}} = 1.15 \qquad \text{(Eq. 31)}$$

Table 2-13. TYPICAL ANALYSIS OF FLUE GAS FROM CONVENTIONAL AND LOW-ODOR RECOVERY BOILERS[19]

Component, %	Conventional	Low-odor
N_2	62.3	73.64
CO_2	12.6	14.9
CO	0.08	0.09
O_2	1.93	2.27
H_2O	23.10	9.1
Temperature, °F	300	400
Dynamic viscosity, $Nt\text{-}s/m^2 \times 10^{-5}$	2.07	2.39

Other important parameters in precipitator sizing are particle size distribution, particle resistivity, the electrical current-voltage data, and particle reentrainment. Available particle size data on the low-odor process indicates mass mean diameters of about 1.5 μm and a standard deviation of about 2.5.[20] These values are very similar to those of particulate from the conventional recovery furnace. Particle resistivity in the two processes is the same order of magnitude, around 10^9 ohm-cm. The electrical data could be different with lower operating voltages on high-temperature, low-odor processes. The peak charging fields would be expected to be lower. This effect would be compensated for, however, by an increase in ion mobility and higher precipitator current. Preliminary calculations indicate that the available electrical data do not explain the differences in precipitator performance caused by greater temperature fluctuations.

The tenacity of the dust and the bulk dust density are very important in quantifying rapping reentrainment losses. Although only qualitative statements can be made in the absence of quantitative measurements, field experience indicates that in the low-odor process the dust adheres very tenaciously to the collecting plates. To dislodge this dust sufficient rapping forces must be applied to produce rapid acceleration parallel to the gas flow (shear action). With heavy rapping, vibrations can be induced perpendicularly to the gas flow direction in addition to the necessary shear action at the plate surface, which result in a scattering of the agglomerate. This can lead to reentrainment of relatively larger fractions of the collected particulate in a low-odor process than in the conventional processes.

Dynamic viscosity of the flue gas determines the drag force on the particles. The higher the temperature, the higher will be the viscosity, resulting in increased drag force on the particles. As shown in equation 29, SCA is inversely proportional to w', the modified migration velocity, according to the precipitator model presented in connection with the conventional recovery furnace process. Assuming that all things are equal in the two processes except the gas dynamic viscosity, one can write

$$\frac{SCA_L}{SCA_C} = \frac{w'_C}{w'_L} = 1.15 \qquad \text{(Eq. 32)}$$

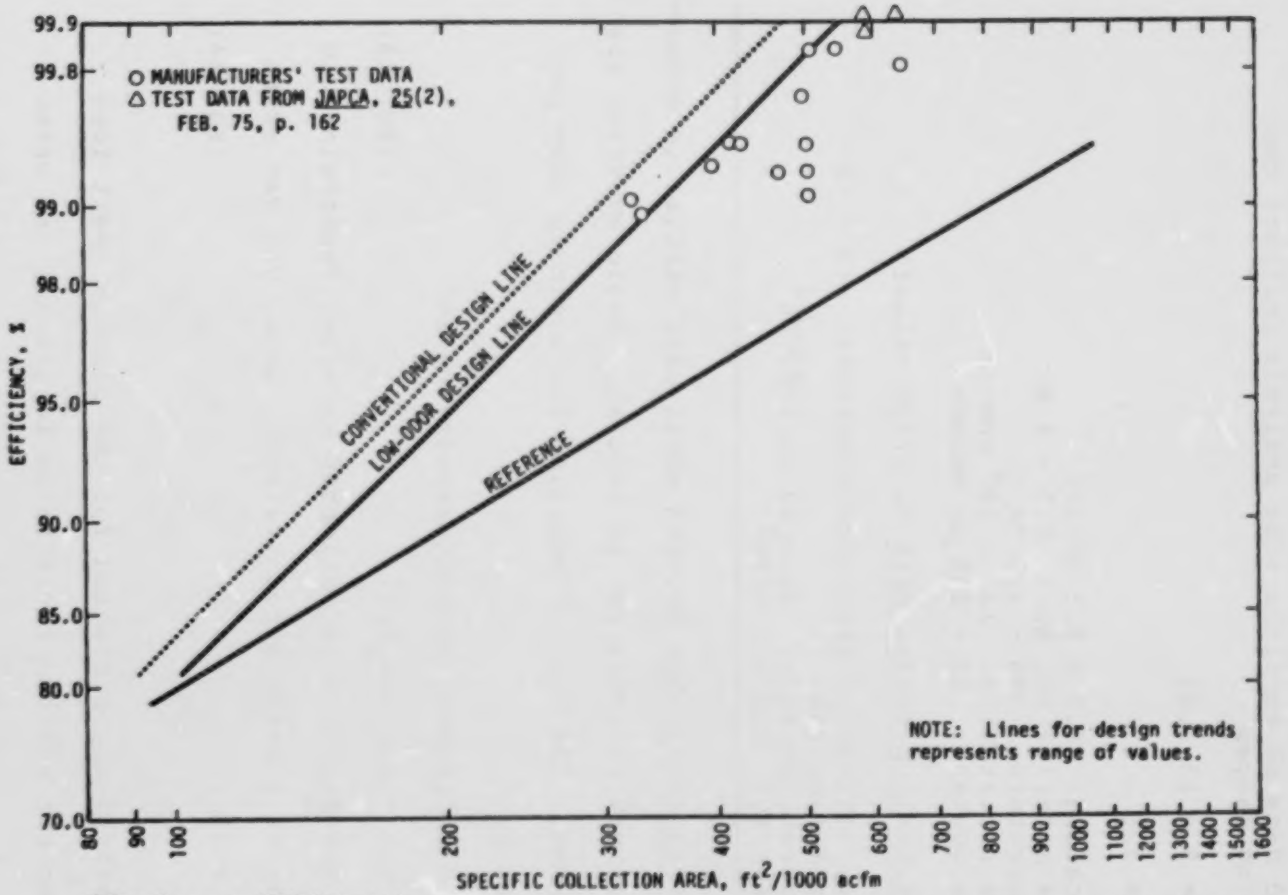
Equation 32 illustrates that a precipitator applied to low-odor process (operating at 400°F) requires an SCA about 15 percent higher than one on a conventional process (operating at 300°F.)

A precipitator design line based on these calculations is shown in Figure 2-14 for precipitator sizing on low-odor recovery furnaces. Additional test data are required to determine the validity of equation 32.

Precipitator Design Correlations for Bark Boilers in the Paper Industry--

The objective here is to outline the design method used to size precipitators applied to collection of bark ash emitted from power boilers. This evaluation does not include emissions from boilers fired with sea-soaked bark materials. It is well known that the low resistivity of bark ash can pose serious collection problems. Reentrainment losses are high. Nevertheless, ESP's have been used successfully on non-salt laden bark boilers. Any theoretical model would overpredict precipitator performance unless the calculated efficiencies are corrected for rapping reentrainment losses as is done in the model presented here.

Details of the bark boiler combustion process are described in Section 2.1.1. For theoretical development purposes the key parameters are summarized in Table 2-14.



* Based on a modified Deutsch equation.

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Figure 2-14. Selected precipitator correlations* for low-odor kraft pulp mill recovery furnaces.

Table 2-14. TYPICAL OPERATING CONDITIONS IN PRECIPITATORS ON BARK/FOSSIL-FUEL BOILERS[13]

Particle size distribution:

Limited data on particle size analysis indicate the following ranges

$\bar{x} = 5 - 15$ (μm)

$\sigma = 2.5 - 4$

Grain loading: 0.5 - 1.5 gr/acf
Particle material sp. gr.: 0.5 - 1.0
Gas temperature: 300 - 400 °F
Particle resistivity: $10^7 - 10^9$ ohm-cm
Moisture content: 10 - 20% by volume

Typical Electrical Operating Data (average values)

Secondary voltage at discharge electrode: 40 - 45 (kV avg.) electrode
Plate current density: 20 - 60 mA/1000 ft^2
Power density: 1.5 - 3 W/ft^2

Theoretical model--The Deutsch model used earlier in connection with recovery furnaces can be used as a basic equation with no reentrainment. The Deutsch equation for a single size particle is given by

η_d' = efficiency without reentrainment

$$= 1 - \exp(-w_d A/Q) \qquad \text{(Eq. 33)}$$

Letting r be the fraction of collected material reentrained in the gas stream as a rapping reentrainment loss, one can write

$$\eta_d = (1-r)\eta_d' \qquad \text{(Eq. 34)}$$

where

η_d = efficiency corrected for the reentrainment loss r.

Therefore, for the entire precipitator length one can write

$$1 - \eta_T = \Pi(1-\eta_d) = \Pi\{1-(1-r)\eta_d'\} \qquad \text{(Eq. 35)}$$

where

η_T = overall collection efficiency of size d

Equation 35 can be further simplified if the following assumptions are made: 1) overall migration velocity remains constant; 2) the fraction of the material reentrained remains constant for different particle sizes; and 3) that the fraction of material reentrained remains constant for each mechanical section.

With these assumptions equation 35 can be written to obtain:

$$1 - \eta_T = \{1 - (1-r)(1 - \exp(-w_d A/Q))\}^n$$

or

$$1 - \eta_T = \{r + (1-r)\exp(-w_d A/Q)\}^n \qquad \text{(Eq. 36)}$$

where

n = number of mechanical sections in the precipitator.

The overall mass collection efficiency of the precipitator can then be determined by integrating equation 36 over the entire particle size distribution. Therefore, mathematically one can write

$$(1-\bar{\eta}) = \int_0^\infty (1-\eta_T) f_1(d)\,dd \qquad \text{(Eq. 37)}$$

Assuming a lognormal inlet particle size distribution, equation 37 can be simplified. The final integration, however, requires a numerical technique to establish the relationship between r on $\bar{\eta}$.

Model application to bark boilers--The method used here is similar to that described above for recovery furnaces.

$$E_o \approx \frac{41 \times 10^3 \times 2}{0.1143} = 5.07 \times 10^5 \text{ V/m} \qquad \text{(Eq. 38)}$$

Using the computer program and Cooperman's correlation for the current-voltage information, we estimate

$E_p \approx 3.7 \times 10^5$ V/m

$\mu \approx 2.5 \times 10^{-5}$ Nt-s/m^2

$\varepsilon_o = 8.854 \times 10^{-2}$ coul/V·m

$w' = 2.216$ s^{-1}

Therefore, for bark ash boilers the theoretical design equation assuming no reentrainment becomes

$$\frac{A}{Q} = \left(\frac{1}{2.216}\right)\left(\frac{\ln(1-\bar{\eta})}{\ln C}\right)^{1/m} \qquad \text{(Eq. 39)}$$

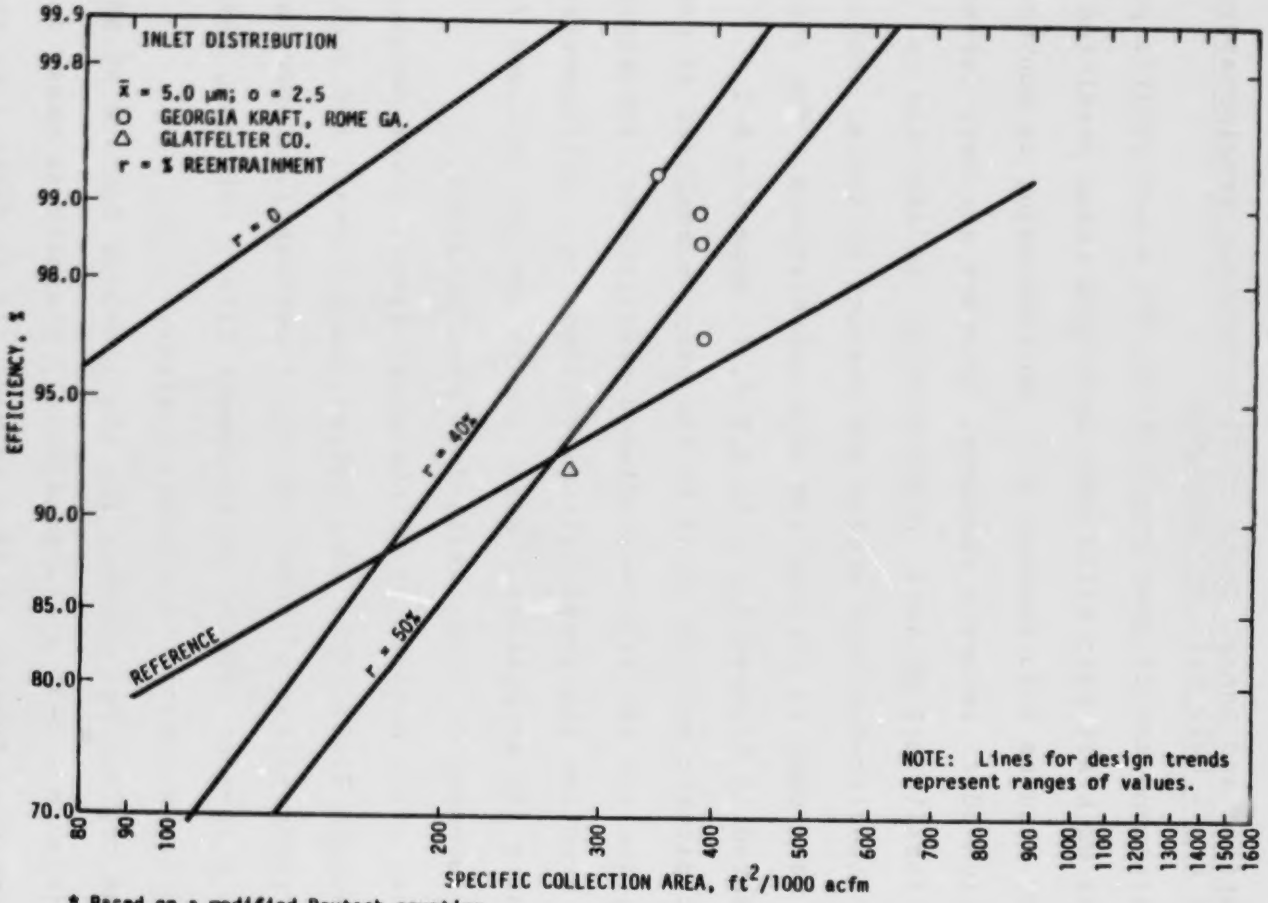
The values of m and C can be determined as explained in the previous section. Assuming $\bar{x} = 5$ µm and $\sigma = 2.5$ the calculated values are

$C = 0.7166$; $m = 0.63$

To convert from mks to English units, the value for A/Q in sec/m in equation 39 is divided by 0.197, thereby obtaining ft^2/1000 acfm.

The plot of SCA versus overall efficiency for bark/fossil fuel-fired boilers is shown in Figure 2-15. The efficiency values with no reentrainment (r=o) over-predict precipitator performance and must be corrected for reentrainment losses. Use of the reentrainment model presented in this section (at r=40 and 50%) shows a closer correlation to available test data on the two installations shown in Figure 2-15. Field data generally show a 40 to 50 percent loss in efficiency due to reentrainment.

The model needs further testing with additional performance test data before it can be widely applied as a design tool for



* Based on a modified Deutsch equation.

Figure 2-15. Selected precipitator design correlations* for bark combination fossil fuel fired boilers.

sizing precipitators applied to bark boilers. In Figure 2-15, use of the model assumes a typical inlet distribution of $\bar{x} = 5$ and $\sigma = 2.5$. The reference line has a slope of 0.5.

2.3.3 Capital and Annual Costs of Electrostatic Precipitators on Kraft Pulp Mill Applications

Capital and annual cost correlations for electrostatic precipitators on kraft pulp mills were developed using predicted SCA's from Figures 2-13 through 2-15, corresponding to conventional (high-odor) recovery furnaces, low-odor recovery furnaces, and bark/fossil-fuel boilers, respectively. In addition to standard Research-Cottrell sizing and costing criteria, computer programs were used to develop the cost correlations. The costs are presented in Figures A.2-1 to A.2-6, in Appendix A-2.

Precipitator capital costs to the user, normalized at year-end 1977, include the flange-to-flange precipitator, structural support, erection and installation, engineering, contingencies, and warranty and acceptance. Heat jackets are not included for recovery furnaces or bark/fossil-fuel precipitators.

Annual costs consist of maintenance, labor, power consumption (assuming $0.03/kWh), administration, overhead, and capital charges (taken at 15% of total capital investment). Depreciation (assuming a 15-year accounting equipment life), interest, insurance, and taxes constitute capital charges.

Since capital investments for the low-odor furnace at 99.8 percent (Figure A.2-3) are approximately the same as those for the conventional furnace at 99.9 percent, it is clear that the low-odor option is more expensive. The difference in efficiencies alone accounts for a 20 percent larger precipitator size (SCA) for low-odor applications. Furthermore, the drag-bottom configuration associated with low-odor applications is more expensive than the wet-bottom used in conventional recovery furnace precipitators.

For the efficiency ranges considered, it appears that the cost of a heat jacket may add up to 5 percent to the cost of the precipitator system as defined above. Use of a heat jacket depends on precipitator capacity, shell surface area, and operating and ambient temperatures.

Annual costs are higher in low-odor (Figure A.2-4) than in conventional (Figure A.2-2) applications. Since capital investments are higher for low-odor precipitators, the capital charges are correspondingly higher. Furthermore, low-odor precipitators have higher power density (1.9 W/ft^2 versus 1.5 W/ft^2 for conventional precipitators) and hence direct operating costs are higher.

2.4 MECHANICAL COLLECTORS

2.4.1 General System Characteristics

This section describes the major parameters that must be considered in the design of a mechanical collector servicing bark/fossil-fuel boilers. The most common type of mechanical collector is the conventional cyclone.

2.4.2 Design Philosophy

Parameters affecting the design of a cyclone[21] are presented in Table 2-15, and described in the text that follows:

TABLE 2-15. PARAMETERS AFFECTING CYCLONE DESIGN[21]

System input	System parameters	System output
Process application	Pressure drop	Overall collection efficiency
Process conditions	Particle size distribution	Capital investment
Applicable emission standard	Inlet gas velocity	Annual cost
	Cyclone body diameter dimension ratios	
	Specific gravity of dust	

Pressure Drop--

Pressure drop is one of the most important factors affecting efficiency and design. The pressure drop across a cyclone varies as the square of the gas volume and is directly proportional to the density of the dust-laden gas. The total pressure drop in a cyclone is the sum of separate losses in the inlet flue, the cyclone body, and the outlet duct.

Particle Size--

The efficiency of a conventional cyclone decreases with decreasing particle size to a point where particle collection is 50 percent at a particle diameter of 5 μm. The finer particles are strongly influenced by turbulence of gas flow and are not collected. The effect of particle size on efficiency of a specific type of cyclone is shown in a fractional efficiency curve, which can be obtained only from test data[22] (See Figure 2-16).

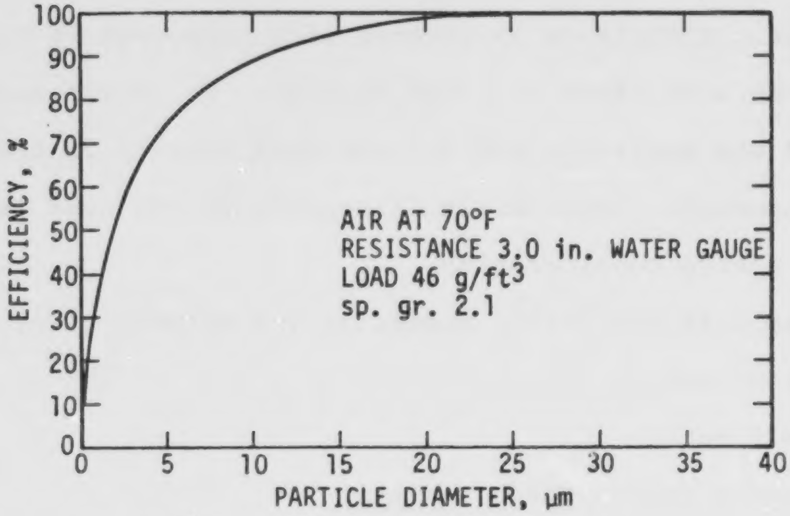


Figure 2-16. Typical fractional efficiency curve.[22]

Cyclone Body and Diameter Dimension Ratios--

A cyclone of relatively higher efficiency and higher pressure drop could be designed by 1) increasing the length of the cyclone, 2) decreasing the width of the inlet, or 3) increasing the ratio of body diameter to outlet diameter, while at the same time reducing the body diameter. Increasing the length of the cyclone body provides a longer residence time for gas in the cyclone and therefore more revolutions of the gas stream. Increasing body length also minimizes efficiency loss due to reentrainment of particles in the ascending vortex. Increasing the ratio of body diameter to the gas outlet diameter effects an increase in efficiency at ratios up to about 3 to 4; above a ratio of 4, the gains are slight but the pressure drop increases.

Specific Gravity of the Dust--

Of the dust physical properties affecting the collection efficiency of a cyclone, specific gravity is one of the most significant. Efficiency is greater with particles of higher density than with those of lower density. It is the specific gravity of the particle, and not the bulk density of the dust that is important. However, bulk density of the dust is an important design consideration.

Tables 2-16 and 2-17[23] summarize the effects of cyclone design parameters.

2.5 WET SCRUBBERS

2.5.1 General System Characteristics

The sources of particulate emissions to which wet scrubbers are applied are smelt dissolving tanks, sludge lime kilns, and more recently combination bark/fossil-fuel boilers at kraft pulp mills, and conveyors and crushers in stone crushing operations. Types of wet scrubbers used are impingement, packed towers, showered mesh mist eliminators, and venturis.

Exhaust gases from a lime kiln normally pass through a mechanical cyclone collector for lime dust recovery and finally through a liquid scrubber for particulate control. The major types of scrubbers used on lime kilns are impingement and venturi scrubbers. Impingement scrubbers have been used extensively for particulate scrubbing on lime kilns because their low pressure drops and low scrubber shower rates minimize operating costs. A disadvantage of the impingement scrubber is a limit on the solids concentration in the scrubber slurry because of plugging potential. They are also less efficient than other scrubbers in removing particulate matter because the gas-liquid contact is less efficient.

Table 2-16. PERFORMANCE TRENDS BASED ON CHANGES IN CYCLONE DESIGN

Change	Performance trend		Cost trend
	Pressure loss	Efficiency	
Increase cyclone size	Down	Down	Up
Lengthen cylinder	Slightly lower	Up	Up
Increase inlet area, maintain volume	Down	Down	No effect
Increase inlet area, maintain velocity	Up	Down	Down
Lengthen cone	Slightly lower	Up	Up
Increase size of cone opening	Slightly lower	Up or down	No effect
Decrease size of cone opening	Slightly higher	Up or down	No effect
Lengthen clean-gas outlet pipe internally	Up	Up and/or down	Up
Increase clean-gas outlet pipe diameter	Down	Down	Up

Table 2-17. EFFECTS OF PHYSICAL PROPERTIES AND PROCESS VARIABLES ON EFFICIENCY

Proportional change	Pressure loss	Efficiency	Cost trend
Gas change			
Increase velocity	Up	Up	Initial cost down Operating cost up
Increase density	Up	Negligible change	Slightly higher
Increase viscosity	Negligible	Down	No effect
Increase temperature (maintain velocity)	Down	Down	No effect
Dust Change			
Increase specific gravity	No effect	Up	No effect
Increase particle size	No effect	Up	No effect
Increase loadings	No effect	Up	No effect

Capital costs of impingement scrubbers are higher than costs of venturi scrubbers on similar installations because the impingement scrubbers are larger and more complex. Newer kraft pulp mills are installing venturi scrubbers on the lime kilns because of their higher particulate removal efficiencies. Venturi scrubbers can operate with slurry water solids concentrations of up to 30 percent by weight without excessive plugging. Some operating characteristics of particulate scrubbers on kraft lime kilns are presented in Table 2-18.[24]

Table 2-18. OPERATING CHARACTERISTICS OF PARTICULATE LIQUID SCRUBBERS ON KRAFT LIME KILNS

Parameter	Scrubber type	
	Impingement	Venturi
Liquid/gas ratio, liter/m^3 (gal/1000 ft^3)	0.54-2.0 (4-15)	1.73-3.21 (13-24)
Slurry solids, % by wt	1-2	10-30
Pressure drop, mm Hg (in. H_2O)	9-13 (5-7)	19-28 (10-15)
Power required,[a] kW per ton/day (hp/ton/day)	0.041-0.049 (0.05-0.06)	0.082-0.099 (0.10-0.12)
Power required,[b] kW per ton/day (hp/ton/day)	(0.13-0.16 (0.16-0.20)	0.27-0.34 (0.33-0.42)

[a] per mass of pulp

[b] per mass of lime

The particulate matter from kraft smelt dissolving tanks consists of both dissolved and undissolved NaOH, Na_2CO_3, and Na_2S. Typical particulate emissions from smelt dissolving tanks are 0.03 to 1.2 kg per Mg of pulp (0.05 to 2.3 lb/ton) following control devices.[25] Most of the smelt tanks that are controlled use mesh demisters and/or packed towers to collect particulate matter from exhaust gases.

Typical operating conditions for two recently installed venturi scrubbers on combination bark/fossil-fuel boilers are summarized below:

Volume acfm	Pressure drop, in. W.G.	L/G (gal/1000 ft^3
74,575 at 390°F	8-10	6.7 - 8.0
174,000 at 395°F	15-20	8.5

The following are operating conditions specified for venturi scrubber operations on crushers:[26]

	Pressure drop, in. W.G.	L/G gal/1000 ft^3
At 20,000 acfm	7-17	9-13
At 70,000 acfm	9-16	9-13

The ranges of pressure drops and L/G ratios are attributed to different levels of scrubber efficiency.

The following are operating conditions specified for venturi scrubbers at conveyor transfer points:[26]

	Pressure drop, in. W.G.	L/G gal/1000 ft^3
At 5,000 acfm	7-12	8-9
At 15,000 acfm	7-12	8-9

Impingement Scrubbers--

In an impingement scrubber the gas stream enters the collector, then passes over a pool of water and impacts the surface of the pool before exiting. Control of the water level is critical to this device. Pressure loss and efficiency are determined by the liquid level. This type of collector functions well in the pressure drop range of 2 to 6 in. Inlet loadings range from 3 to

14 gr/acf, and outlet emissions range from 0.4 to 1.5 gr/acf. Although it is advantageous to attempt sludge separation inside the scrubber, the dust tends to stay in suspension in the sump because of air turbulence. Nevertheless, where particles are large and settle easily, this can be a very successful arrangement. Because the liquid in the pool serves as the scrubbing medium, the liquid discharge rate can be adjusted according to the desired solids content in both the retained liquid pool and the discharge sidestream.[27]

Packed Towers--

Packed vertical towers contain materials on which the gas and liquids are contacted. Raschig rings are the most common packing materials. The gas stream can be introduced across, with, or against the flow of liquid. In the crossflow design, liquid is introduced at the top of the packing, while the gas moves horizontally through it. This arrangement helps to wash any accumulated contaminants off the packing surface. In the cocurrent flow design, gas and liquid enter at the top of the scrubber and leave at the bottom. The exit gas stream then passes through an entrainment separator or mist eliminator. In the countercurrent design, the liquid flows down through the bed, wetting the packing to provide interfacial surface area for mass transfer of the pollutant with the gas. The gas then flows up the bed countercurrent to the liquid. Highest pressure drop and lowest gas flow are achieved with the countercurrent unit; gas flow capacity is greatest in the cocurrent unit, and operation of the crossflow tower is unpredictable. All three designs are subject to particulate buildup on the walls. Clean liquid and low dust loading are desirable. Water is introduced above the packing by weirs or spray nozzles. Packed towers must be operated within a narrow range of conditions to prevent maintenance problems. If either the liquid or gas rate is accelerated, liquid holdup occurs and pressure drop increases. If gas velocity is further accelerated, flooding occurs, accompanied by high pressure drop and entrainment of liquid in the gas stream. Buildup of solids in the packing is a serious problem. Unlike other scrubbers, packed tower internals are not easily accessible.[28]

Showered Mesh Mist Eliminators--

Particulate matter consisting of dissolved and undissolved NaOH, Na_2CO_3, and Na_2S is emitted from the smelt tank with the flow of gases. The mist eliminator consists of fine wire mesh screens approximately 30 cm (1 ft) thick. Droplets condense from the gas on the wire mesh screens, which may be placed in series as determined by the absorption efficiency required.

Collection efficiency can be increased by following the mesh mist eliminator with a packed tower or by using a packed tower only. Table 2-19 summarizes the efficiency of mesh demisters used in conjunction with another wet scrubber on smelt dissolving tanks.[29]

Table 2-19. PERFORMANCE CHARACTERISTICS OF SHOWERED MIST ELIMINATORS ON SMELT DISSOLVING TANKS[29]

Control device	Collection efficiency, %	Emission rate, lb/ton
Pad entrainment	71.8	(0.05)
Separator	77.2	(0.15)
Separator	77.8	(0.63)
Separator	90.2	(2.3)
Separator	93.4	(1.2)
Separator	70.8	(1.58)
Pad plus shower scrubber	96.2	(0.41)
Pad plus packed scrubber	91.9	(1.20)
Packed scrubber	98.1	(0.05)

Venturi Scrubbers--

In conventional terminology, the venturi scrubber is categorized as a gas atomized spray scrubber. The collection process mainly relies upon acceleration of the gas stream to provide impaction and intimate contact between the particulates and fine liquid droplets generated as a result of gas atomization. Basically, this is a high energy consuming device designed for high particulate collection efficiency. Typically, the pressure drop is on the order of 10 to 20 in. of water or more in kraft pulp mill applications. Collection efficiency increases with the pressure drop and liquid-to-gas circulation ratio. However, there is an optimum L/G ratio above which additional liquid is not effective at a given pressure drop. In this device the pressure drop can be increased by increasing the gas velocity.

The system characteristics and design philosophy for wet scrubbers applied to stone crushing and conveyor transfer points are similar in many respects to the information presented for kraft pulp mill applications. One difference is that hoods and sometimes extensive ductwork are required to collect and transfer emissions from primary, secondary, and tertiary crushers to the scrubber inlet. The system consists of a venturi scrubber, recirculating tank, pumps, slurry settler, slurry filter, and induced-draft fan. A system for conveyor transfer points requires less ductwork than one for crushing operations.

2.5.2 Design Philosophy

Where local emission regulations are strict regarding kraft pulp mill and stone crushing operations, venturi scrubbers are often used when scrubbers are specified.

In design of a venturi scrubber, the key parameters affecting particulate collection are gas velocities and gas flow rates, particle size distribution, pressure drop, and liquid-to-gas ratio. In addition, the following information is also required for selection of equipment.

(a) Gas handling capacity per module.

(b) Total number of modules required.

(c) Capital investment; annual costs.

(d) Water requirement; water recirculation.

(e) Availability of the equipment or necessary downtime.

(f) Fractional collection efficiency of the device.

(g) Total power consumption as a fraction of the generated power.

Velocity/Gas Flow Rate--

Sizing of a venturi scrubber is often based on the inlet gas velocity and flow rate. Usually, the inlet gas velocity is about 60 ft/sec while the inlet gas rate is dependent on the designed scrubber diameter. Typical scrubber diameters are under 10 ft. If the gas rate is too high to be accommodated by one scrubber, several scrubbers should be designed for the system.

The gas velocity through the venturi will decrease more at higher temperatures than at lower temperatures. Also, at higher temperatures higher liquid-to-gas ratios are required for heat transfer.

L/G Ratio--

The L/G ratio typically ranges from 1 to 15 gpm/1000 acf for all of the scrubbers discussed and is basically a function of inlet gas temperature, inlet solids content, and method of water introduction.[30] At higher inlet gas temperatures, evaporation of the scrubbing liquor may occur at the point of gas/liquid contact. Where inlet dust loading is heavy, the L/G ratio should be increased to minimize solids buildup and plugging of drains. Although pressure drop across the venturi is essentially independent of specific design, the less efficient methods of water introduction will require additional scrubbing liquor to meet efficiency requirements.

Pressure Drop--

Design for a given application requires consideration of throat velocity and L/G ratio to achieve the maximum collection efficiency for the energy spent. The energy spent is often indicated by the gas pressure drop across the scrubber, which ranges typically from 10 to 20 in. H_2O for venturi scrubbers, 2 to 6 in. for impingement scrubbers, 1 to 2 in. for packed towers, and 0.05 to 1 in. across a 4-in. bed in a mesh mist eliminator.[31] Achieving a given pressure drop depends on the relationships between throat velocity and L/G ratio. Actually, only one set of conditions will yield the maximum efficiency for the energy spent. That one set of conditions is the only one that will create maximum droplet surface with a minimum L/G ratio during atomization.

Particle Size Distribution--

The particle size distribution in the inlet gas stream, a key factor in control equipment design, often varies with process operating conditions. Data on fractional collection efficiency for submicron particles are particularly difficult to obtain. When one is speaking of greater collection efficiencies, it should be clear that this means increased fractional collection efficiencies in the submicron particle size range.

Materials Selection--

Because scrubber slurry and the gas streams often carry abrasive solids that can erode, selection of construction materials must be considered. Where abrasion-resistance requirements exceed the limits of stainless steel, the designer may select fiberglass reinforced plastic (polyester). Abrasion-resistent liners are also needed to withstand high temperatures.

Mist Eliminator--

Mist eliminators are necessary to control undesirable emissions of liquid droplets from the scrubber, caused by atomization, and carryover of some liquid during scrubbing.

Because of the solids in the scrubber liquor, entrainment of water droplets can cause system operating problems as well as liquid losses. Suspended or dissolved particles can cause solids buildup, and suspended solids can cause erosion. Among the many problems caused by buildup of solids is the resultant increase in pressure drop.

2.5.3 Correlations

Another difficulty in designing venturi scrubbers, impingement scrubbers, packed towers, and shower mesh demisters is the unavailability of reliable design models. Nearly all of the published scrubber models show either by formulas or by design curves that the empirical correlations are based on inertial impaction or overall power input. Usefulness of empirical models is often limited because both control and process variables vary within certain ranges. Therefore, extrapolating design data from empirical models involves some risk. Moreover, particulate collection in all four types of scrubbers depends not only on particle size distribution but also on particulate properties, such as specific gravity, wetability, agglomeration, and solubility in the scrubber liquid.

The K-factor in Brink's model,[32] f-factor in Calvert's model,[33] and the β and γ constants in the Power-Law model[34] are all empirical constants encompassing many of the parameters upon which particulate collection depends. Which model is suitable is a matter of judgment. In addition, other mechanisms such as diffusion may control collection of submicron particles.

The model used in this report was developed by Research-Cottrell and is presented in detail in Section 4.2.2. It has been used for the general class of gas atomized spray scrubbers. It is specifically intended to model flooded-disc scrubbers. Although the model was developed specifically for fly ash applications, we extrapolate for use here in the absence of fractional efficiency data on kraft pulp mill and stone crushing applications. The similarity of some of the dust properties and required pressure drops indicates that extrapolation appears reasonable.

The L/G ratio, pressure drop, and efficiencies calculated from this model are used as a basis for capital and annual cost evaluation, presented in Section 2.5.4. An optimum L/G ratio was chosen, and the pressure drop increased to achieve the desired collection efficiency.

2.5.4 Capital and Annual Costs of Venturi Scrubbers on Kraft Pulp Mill and Stone Crushing Operations

Capital and annual costs are presented in Appendix A-5. These are based on application of a flooded-disc scrubber to collect particulate emissions. The computer model is based on the following assumptions.

1. The major equipment included in the venturi scrubber system consists of a flooded disc scrubber and a mist eliminator with a sump tank, one forced-draft fan with driver, and two slurry pumps with drivers. The auxiliaries included are ductwork, expansion joints, piping, and instrumentation.
2. The material of construction for both major equipment and auxiliaries is carbon steel without linings.
3. The temperature of the flue gas is 400° to 500°F in lime kilns and 200°F in smelt dissolving tanks. Control systems applied to stone crushing operations operate at ambient temperature.
4. The total capital investment for the system consists of the major and auxiliary equipment costs, tax and freight (average), installation costs, engineering, and contingency.
5. The annual costs consist of:

   (1) Fixed charges (at 15 percent of the total capital investment) including depreciation, interest, insurance, and taxes.

   (2) Maintenance (at 5 percent of capital investment) including materials and labor.

   (3) Labor cost (at $9 per man-hour assuming 3500 man-hours per year required).

   (4) Administration (at 10 percent of labor cost).

   (5) Water usage (at $0.30 per 1000 gal).

   (6) Electricity usage (at $0.03/kWh)

(7) Overhead cost (at 10 percent of the total cost of water, electricity, labor, and maintenance).

6. Cost estimates are based on costs of materials and labor in the 4th quarter of 1977.
7. Dust specific gravity is taken to be 2.4 g/cm^3 for kraft pulp mills and 2.7 g/cm^3 for stone crushing operations.

Figure 2-17 shows the system components and boundaries.

Figures A.3-1 and A.3-2 indicate the capital and annual costs, respectively, for venturi scrubbers on sludge lime kilns. For a system with high gas temperature and high required efficiency of particulate removal, a gas precooler may be required to reduce the effects of high temperatures on scrubber performance as well as on cost of fans. The power consumption of the fan has a considerable effect on the total operating cost in high-pressure-drop operations.

Figures A.3-3 through A.3-6 present capital and annual costs of venturi scrubbers applied to non-salt and salt laden bark/fossil fuel fired boilers respectively. The presence of salt in the fuel can severely limit the efficiency of the venturi scrubber at the maximum estimated pressure drop of 20 inches of water. This reduced efficiency has been confirmed by field tests of a venturi scrubber at similar pressure drops and L/G ratio as the data presented here.

The result of having salt in the fuel is that capital and annual cost for the salt laden venturi scrubbers are higher

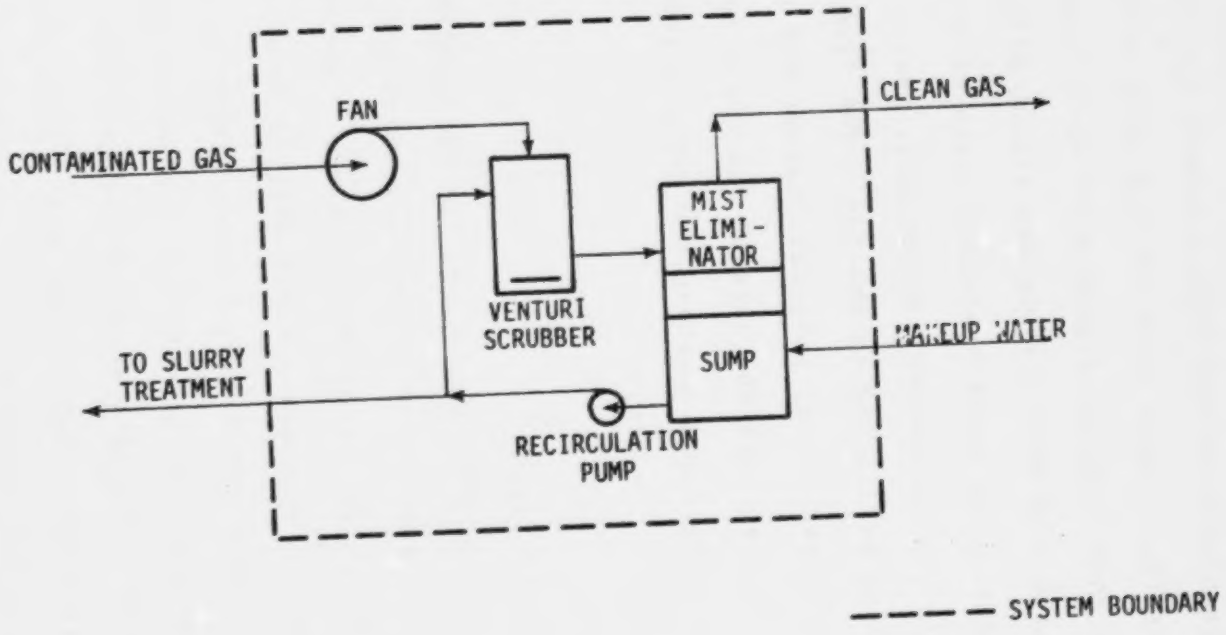

CONTAMINATED GAS
FAN
VENTURI SCRUBBER
MIST ELIMINATOR
SUMP
CLEAN GAS
MAKEUP WATER
TO SLURRY TREATMENT
RECIRCULATION PUMP
SYSTEM BOUNDARY

Figure 2-17. Venturi flooded disc scrubber system.

than the non-salt scrubbers, but far less removal of particulate, is provided.

Since the particles emitted from crushers are coarser than those from conveyors, a lower pressure drop will effect a higher collection efficiency (compare Figure A.3-7 with Figure A.3-9). Figures A.3-8 and A.3-10 show clearly the strong effect of electric power consumption on total operating costs of both crushers and conveyors. In high-efficiency operations, nearly all of the power consumption is attributed to the fan. The fixed charges, such as equipment depreciation, interest, taxes, and insurance, are considerably smaller than the cost of fan operation. Labor, maintenance, water usage, and overhead are grouped into the "others" category.

2.6 FABRIC FILTERS

2.6.1 System Characteristics

Within the kraft pulping operation, the application of fabric filtration for control of particulate emissions is limited to bark or bark/fossil fuel-fired power boilers. The design parameters discussed in this section are derived from three known baghouse installations at two mills, Simpson Timber Company in Shelton, Washington, and Long Lake Lumber Company in Spokane, Washington. A fourth baghouse system has recently been purchased by a Georgia-Pacific mill in Bellingham, Washington, but is not yet installed. Table 2-20 lists the pertinent design criteria for power boiler applications based on two of the currently operational systems and the proposed new unit.

Table 2-20. DESIGN PARAMETERS FOR KRAFT PULP POWER BOILER BAGHOUSES

	Simpson Timber	Long Lake Lumber	Georgia-Pacific
Volume flow rate, acfm	230,000	25,000	180,000
Inlet gas temperature, °F	500	400	440
A/C ratio, ft^2/acfm	4.5	4.0	4.0
Bag cleaning method	Pulse jet	Pulse jet	Pulse jet
Pressure drop, in. H_2O	9-9.5	5.8-6.8	[a]
Bag fabric	Teflon coated fiberglass	Nomex	Teflon coated fiberglass
Precollector	Mechanical cinder collector	None	None
Material handling system	Screw conveyor	Screw conveyor	Screw conveyor

[a] Collector not yet installed.

Fabric filtration is the preferred method of particulate control in the crushed stone industry because of the dry, inert nature of the emitted dust collected at ambient conditions. Also, since the captured dust is often used as a stone product or is recycled within the plant, baghouses are ideally suited to this industry. The collectors used to control the various unit operations employ the same basic design parameters and usually differ only in size depending on the number of ventilation points in the system. Typical design parameters for baghouses serving drilling, crushing, screening transfer operations are shown in Table 2-21.[5]

Data gathered by the EPA during emission tests on the 12 baghouse units (listed in Table 2-21) used to control a variety of rock types, including limestone, traprock and cement rock, indicated that the size distribution of particulates collected, the rock type processed, and the facility controlled do not substantially affect baghouse performance.

Parameters important to fabric filter system design include air-to-cloth ratio, pressure drop, cleaning mode and frequency of cleaning, composition and weave of fabric, degree of sectionalization, type of housing, and gas cooling. Baghouses are relatively insensitive to process variables such as chemical composition (providing that the correct bag fabric is chosen), particle size, electrical resistivity, etc.; thus, there tends to be very little substantial design difference from one application, or indeed from one manufacturer, to the other, when comparing

Table 2-21. PROCESS FACILITIES CONTROLLED BY BAGHOUSE UNITS TESTED

Facility	Rock type processed	Baghouse specifications			Process facilities controlled
		Type	Filtering ratio	Capacity, scfm	
A1	Limestone	Jet pulse	5.3:1	26,472	Primary impact crusher
A2	Limestone	Jet pulse	7:1	15,811	Primary screen
A3	Limestone	Jet pulse	7:1	2,346	Conveyor transfer point
A4	Limestone	Jet pulse	5.2:1	10,532	Secondary crusher (cone) and screen
B1	Limestone	Shaker	3.1:1	5,784	Primary impact crusher
B2	Limestone	Shaker	2.1:1	18,197	Scalping screen, secondary cone crusher, hammermill, two tertiary cone crushers, two finishing screens, five storage bins, and six conveyor transfer points
C1	Limestone	Shaker	2.3:1	7,473	Primary jaw crusher (discharge), scalping screen, and hammermill
C2	Limestone	Shaker	2.0:1	6,543	Two finishing screens and two conveyor transfer points
D1	Traprock	Shaker	2.8:1	31,863	Scalping screen, secondary cone crusher, two sizing screens, two tertiary cone crushers, and several conveyor transfer points
D2	Traprock	Shaker	2.8:1	25,960	Finishing screen and several conveyor transfer points
E1	Traprock	Jet pulse	5.2:1	14,748	Two sizing screens, four tertiary cone crushers, and several conveyor transfer points
E2	Traprock	Jet pulse	7.5:1	21,122	Five finishing screens and eight storage bins
G	Limestone	Shaker (manual)	2.5:1	633	Rotary drill

baghouses with the same cleaning mechanism. Differences that do exist are generally related to maintenance (e.g., number of bag rows accessible from a given interior walkway; method of bag cuff attachment to cell plate; etc.). Pertinent baghouse design criteria are briefly discussed below.

Air-to-Cloth Ratio--

A major factor in the design and operation of a fabric filter, the air-to-cloth (A/C) ratio, is the ratio of the quantity of gas entering the filter (ft^3/min) to the surface area of the fabric (ft^2). The ratio is therefore expressed as ft^3/min per ft^2, or sometimes also as filtering velocity (ft/min). Most often only the first member of the ratio term is given, e.g., an A/C ratio of 1.5 implies 1.5 ft^3/min per 1.0 ft^2. In general, lower ratios are used for filtering of gases containing small particles or particles that may otherwise be difficult to capture. Selection of the ratio is based on industry practice or the recommendation of the filter manufacturer.

Design A/C ratios for power boiler fabric filters are about 4/ or 5/1. The three units in operation have A/C ratios of 4/1, 4.8/1, and 4.5/1. The new Georgia-Pacific baghouse will have a 4/1 net A/C ratio. Most of the particulate emitted from bark boilers tends to be in the submicron to 10 μm size range. Thus, enough of the larger particles are present to allow use of a fairly high A/C ratio, but the amount of fines in the mix prevents the A/C ratio from being raised much further. Higher ratios may result in excessive pressure drops. An example of this problem is seen at one of the installations at Simpson Timber. The pressure drop is 3 in. above design and the particulate size distribution is skewed largely toward the submicron range (much of the particulate consists of NaCl from the sea-soaked bark).

Design A/C ratios for fabric filters on crushed stone operations range from 5.0/1 to 7.0/1 for pulse jet units and 2.0/1 to 3.1/1 for shaker units.

Pressure Drop--

Pressure drop in a fabric filter is caused by the combined resistances of the fabric and the accumulated dust layer. The resistance of the fabric alone is affected by the type of cloth and the weave; it varies directly with air flow. The permeability of various fabrics to clean air is usually specified by the manufacturer as the air flow rate (ft^3/min) through 1 ft^2 of fabric when the pressure differential is 0.5 in. H_2O in accordance with the American Society of Testing and Materials (ASTM). At normal filtering velocities, the resistance of the clean fabric is usually less than 10 percent of the total resistance.[35] The spaces between the fibers are usually larger than the particles that are collected. Thus the efficiency and low-pressure drop of a new filter are initially low. After a coating of particles is formed on the surface, the collection efficiency improves and the pressure drop also increases. Even after the first cleaning and subsequent cleaning cycles, collection efficiency remains high because the accumulated dust is not entirely removed.

The pressure drop through the accumulated dust layer has been found to be directly proportional to the thickness of the layer. Resistance also increases with decreasing particle size.[35] Even though several studies have been devoted to filtration theory, it is difficult to relate collection efficiency and pressure drop on an industrial scale.

The range of operating pressure drop for bark boiler baghouses is 6 to 12 in. H_2O, and it is preferable to operate at the lower end of this range.

Pressure drops across fabric filters in crushed stone operations from respondents in this study, fall in the range of 2 to 8 in. H_2O. Pressure drops are normally higher in collectors used on tertiary crushing and screening operations than in those used on primary crushing because of the smaller particle sizes encountered.

Cleaning of Fabric Filters--

Table 2-22 shows various cleaning methods that are used to remove collected dust from fabric filters to maintain a nominal pressure drop of 2 to 6 in. H_2O. A discussion of the operation of various cleaning methods is presented in Section 3.3.

Each method has advantages and disadvantages. For example, when reverse air is used with a ringless bag, it creases the bag considerably and narrows the cross sectional area available for reverse flow to occur. This can be alleviated by use of anti-collapse rings. The mechanical shaker is usually applied in a horizontal fashion to minimize flex abrasion (fiberglass bags),

Table 2-22. CHARACTERISTICS OF FABRIC FILTER CLEANING METHODS[35]

Cleaning method	Uniformity of cleaning	Bag attrition	Equipment ruggedness	Type fabric	Filter velocity	Apparatus cost	Power cost	Dust loading
Shake	Average	Average	Average	Woven	Average	Average	Low	Average
Reverse air	Good	Low	Good	Woven	Average	Average	Med. low	Average
Plenum pulse	Good	Low	Good	Felt, woven	High	High	Med.	High
Pulse-jet	Average	Average	Good	Felt, woven	High	High	High	Very high
Vibration, rapping	Good	Average	Low	Woven	Average	Average	Med. low	Average
Sonic assist	Average	Low	Low	Woven	Average	Average	Med.	

which shortens the life of glass fabric. The pulse jet method, which uses jets and short bursts of compressed air, dislodges the dust from the bag wall during filtering to eliminate off-line cleaning.

The reverse air method is the most gentle of the three methods discussed above, and it promotes longer bag life. However, this method alone may not provide adequate cleaning and may be used in combination with shake or pulse jet (with less pressure) methods to increase the effectiveness of cleaning and minimize bag wear.

All three baghouse installations on bark boilers use pulse jet as the cleaning mechanism. Simpson Timber Company initially used reverse air and pulse jet for cleaning at its Shelton, Washington, baghouse, but discontinued the reverse air after finding it to be ineffective. Installations in the crushed stone industry use pulse jet and shaker mechanisms in about equal numbers.

Frequency of Cleaning--

The cleaning cycle should be as short as possible so that no sizable portion of the total fabric will be out of service at any given time. With shake cleaning equipment, for example, a common ratio of cleaning to deposition time is 0.1 or less.[36] With a ratio of 0.1, 10 percent of the compartments in the baghouse are out of service at all times during operation. Therefore, the frequency of cleaning should be designed to minimize this ratio. As mentioned previously, with pulsing equipment, the cleaning time is very brief, yielding a very low ratio of cleaning time to filtering time.

Selection of Fabric--

Selection of fabric is generally based on the operating temperature and on resistance of the fabric to abrasion and corrosion. Table 2-23 shows typical characteristics of various fabrics, which include cotton, wool, fiberglass, and other man-made fibers.[35] Many fabric weaves are available; or the fabric may be felted, a process whereby the identity of the separate yarns tends to be replaced by a more uniform mat. Felted fabrics are almost always cleaned by reverse jet or pulse jet methods. Fabric characteristics may also be altered by further treatment for specific purposes, such as to decrease adhesion or improve wearability. Silicones are often used on fiberglass to reduce abrasion.

Since inlet gas temperatures on kraft pulp mill power boilers range as high as 500°F, the bag fabric must be heat-resistant. The two Simpson Timber units contain Teflon B-coated fiberglass bags for operation at 500°F. The Long Lake baghouse uses Nomex bags and operates at a temperature of about 410°F. The new unit at Georgia-Pacific will use Teflon coated fiberglass for operation at 440°F. The preferred cleaning mechanism for the collector is pulse jet (flex cleaning), which allows for maximum filtering time and minimum interruption of the filtering flow. It also allows for a slightly smaller-sized collector.

At temperatures below 275°F, as is the case in the crushed stone industry, polyester is preferred.

Table 2-23. CHARACTERISTICS OF VARIOUS FABRICS[35]

Fiber	Operating exposure, °F		Supports combustion	Air permeability,[a] $ft^3/min/ft^2$	Composition	Abrasion[b]	Mineral acids[b]	Organic acids[b]	Alkali[b]	Cost rank[c]
	Long	Short								
Cotton	180	225	Yes	10-20	Cellulose	G	P	G	G	1
Wool	200	250	No	20-60	Protein	G	F	F	P	7
Nylon[d]	200	250	Yes	15-30	Polyamide	E	P	F	G	2
Orlon	240	275	Yes	20-45	Polyacrylonitrile	G	G	G	F	3
Dacron[d]	275	325	Yes	10-60	Polyester	E	G	G	G	4
Polypropylene	200	250	Yes	7-30	Olefin	E	E	E	E	6
Nomex[R d]	425	500	No	25-54	Polyamide	E	F	E	G	8
Fiberglass	550	600	Yes	10-70	Glass	P-F	E	E	P	5
Teflon[R d]	450	500	No	15-65	Polyfluoroethylene	F	E	E	E	9

[a] ft^3/min per ft^2 at 0.5 in. W.G.

[b] P = poor, F = fair, G = good, E = excellent.

[c] On a scale of 1 (lowest) to 9 (highest) cost.

[d] DuPont registered trademark.

Degree of Sectionalization--

Design of fabric filter sectionalization (the number of separate filter compartments) requires knowledge of the variation in gas flow with respect to process or plant ventilation, the sizes of commercially available units, and the expected frequency of maintenance.[36] Individual compartments in small collectors may contain as little as 100 ft^2 of fabric surface, although some large units with a capacity of 50,000 ft^3/min may have only one compartment.[36] Except in reverse jet and pulse jet units, at least one compartment in any collector is out of service during the cleaning cycle.

Filter Housing--

Configuration of the filter housing depends on the required fabric surface area and on the temperature, moisture content, and corrosiveness of the gases. When the baghouse is designed so that the dirty gas enters the inside of the bags under positive pressure, housing may be needed only for weather protection or for emission measurements.

The floor area required for baghouses depends on the filtering surface area, size of the bags, and spacing between bags. For example, 1750 ft^2 of filtering area can be provided in about 80 ft^2 of floor area by using bags 6 in. in diameter and 10 ft long, and allowing 4 in. between bags. If 12-in.-diameter bags are used, they must be about 14 ft long to provide the same filtering area in the same floor space, though 12-in.-diameter bags can easily be obtained in lengths of 20 ft or more when there is adequate head room. This configuration (12 in. x 20 ft) would provide a baghouse having about 2500 ft^2 of filtering area in the same floor space (80 ft^2).[37] Because the length/diameter ratio affects the stability of vertical bags, care must be taken to ensure that bags do not rub together during operation or cleaning. In general the length/diameter ratio ranges from 5 to 40,[35] but more commonly is between 10 and 25. Respondents in this study indicated a range of 17 to 31 for the length/diameter ratio.

Design consideration must be given to adequate space for the collecting hopper below the filter bags. Hoppers are commonly designed with 45-degree or 60-degree sloping sides to provide adequate sliding, and with some dusts a 70-degree slope is required. Dust collected in the hopper can be removed by screw conveyors, rotary valves, trip gates, air slides, and other methods.

The most common construction material for the housing is steel; other materials, such as concrete and aluminum, are also used. Corrugated asbestos cement paneling is often used for the exterior roofing and siding of the housing in combination with interior walls and partitions of steel.[37]

Gas Conditioning or Cooling--

Exhaust gases are often too hot to go to the baghouse immediately, so they are cooled before entering the filtration system. Gas cooling generally is not required for kraft pulp mill power boilers, because most are equipped with air preheaters. Likewise crushed stone processes do not require gas cooling.

2.6.2 Correlations

As stated earlier, it is difficult to establish correlations between fabric filter design parameters and specific processes because the fabric filters used in the various applications are very similar. Thus only capital and annual costs are presented here.

2.6.3 Capital and Annual Costs of Fabric Filters

Bark/Fossil Fuel-Fired Boilers--

Only minimal data are available to define capital and annual costs for fabric filtration systems serving pulp mill power boilers. The only reliable cost information was provided by Simpson Timber Company. Their two fabric filters, having capacities of 100,000 cfm and 130,000 acfm with a total cloth filtration area of 55,315 ft^2, were purchased and installed at a cost of $1.9 million in 1976. This cost is equivalent to $8.25/acfm or $34.35/$ft^2$ of cloth.

The annualized cost of operation of the two collectors could not be isolated from other plant operation disbursements, but the annual maintenance costs are estimated to be about $75,000. Most of this expense was related to bag replacement (600 bags changed in the past year).

Crushed Stone Industry--

Deriving typical costs of a fabric filtration control system in crushed stone operations is complex. Each plant represents unique problems in terms of materials, equipment, plant layout or size, tonnages processed, local conditions, and air pollution control regulations. In addition, there are permanent and mobile crushing operations.

The capital and annual cost estimates for particulate control in the crushed stone industry are abstracted from a recent PEDCo report prepared for U.S. EPA.[38] The three control systems considered are fabric filters, wet suppression system, and a combination fabric filter/wet dust-suppression system. Cost analyses of these control systems are applied to three sizes of model plants: a 200-ton/h portable plant, a 300-ton/h stationary plant, and a 600-ton/h stationary plant. Costs represent retrofitted systems. These model plant sizes represent typical plant sizes, based on industry data, and corresponding control system design and configuration.

Installed capital costs reflect December 1977 prices. These costs were obtained by averaging price quotations from several equipment manufacturers for each system design.[39]

Total costs of equipment for fabric filter systems include gas cleaning equipment, fan system, hopper, and a screw conveyor with an air lock. Direct costs represent equipment and installation costs, including foundation and support, ductwork, stack, piping, insulation, painting, and electrical work.

Costs of equipment for wet dust-suppression systems include the dustsuppression equipment, water filter and flush, high-pressure truck-dump station, shelter house, and equipment winterization. Direct costs include equipment, foundation and supports, piping, insulation, and electrical work.[40]

Costs of other equipment for fugitive dust control are itemized separately. Indirect costs include engineering, construction and field expenses, construction fees, startup, performance test, and contingencies. Total capital cost is the sum of direct and indirect costs. Contingencies and retrofit penalties are included in the direct and indirect costs.[40]

Production losses during startup as well as research and development costs are difficult to estimate and are not included in the capital costs.

Bases for Annual Cost Estimates--

Annual cost includes direct operating costs and fixed costs. Direct operating cost components are power, water, maintenance, operating labor, and supplies. Fixed cost components are payroll, indirect costs, insurance, taxes, and capital recovery.

Return on investment and product recovery credits are insignificant and therefore are not included in annual costs.

Several equipment manufacturers estimated the annual costs, which reflect December 1977 prices.[40] Depreciation and interest on the capital investment are computed by means of a capital recovery factor that is dependent on the operating life of the equipment and the current interest rate. Unless otherwise stated, an operating life of 15 years and an annual interest rate of 10 percent are assumed to yield a capital recovery factor of 13.2 percent of the capital costs.

Table 2-24 presents the bases for computing annualized costs for most cost components.

Table 2-24. ANNUAL COST COMPONENTS FOR FABRIC FILTER CONTROL SYSTEM[38]

Cost component	Basis
Direct operating costs	
Utilities	
Water	$0.25/1000 gal
Electricity	$0.04/kWh
Operating labor	
Direct	$10/man-hour
Supervision	15% of direct labor
Maintenance and supplies	
Labor and materials	6% of capital costs
Supplies	15% of labor and materials
Fixed costs	
Plant overhead, payroll, taxes, insurance	4% of capital cost
Capital recovery; 15 years at	13.2% of capital cost

Fabric Filter Control System--

Model plant parameters--Discrete emission point-sources (sizing and transfer operations) controlled by fabric filtration are conveying, packaging, screening, milling, and pulverizing operations.

Figure 2-18 indicates the varieties of combined exhaust flow rates from point sources in proportion to plant capacity. Table 2-25 presents process parameters and emission characteristics of the three model plants.

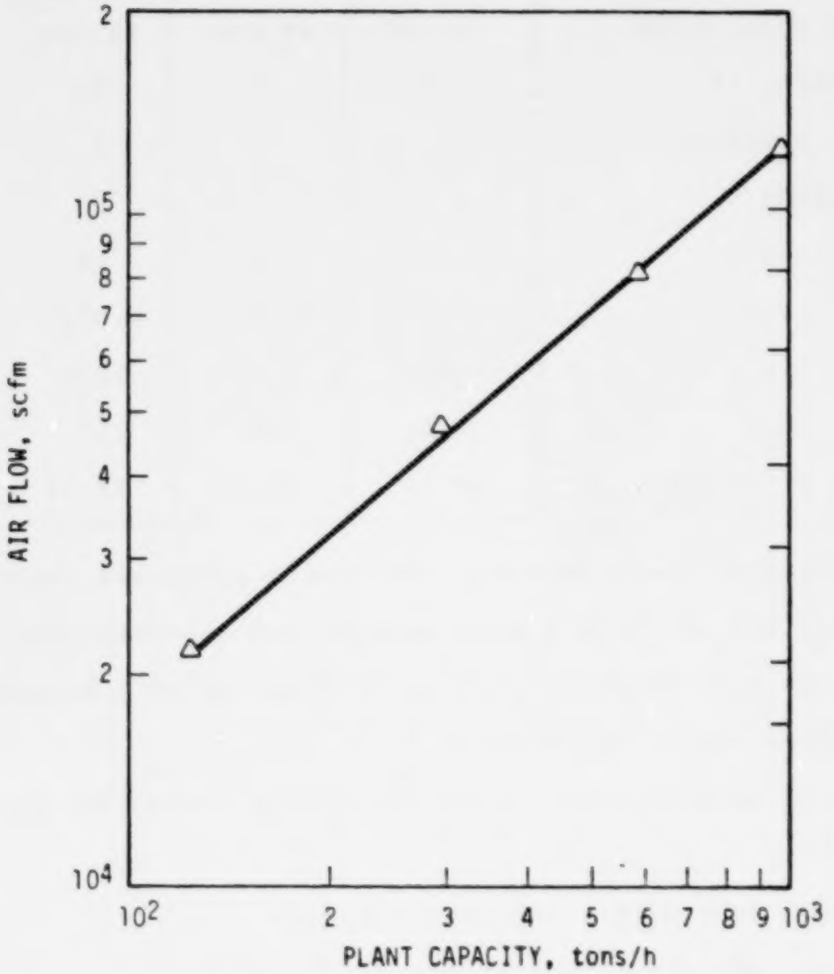


Figure 2-18. Exhaust gas volumes at various plant capacities.[39]

Table 2-25. CHARACTERISTICS OF EXHAUST GAS FROM MODEL SIZING AND TRANSFER OPERATIONS[39,40]

Plant size, tons/h	200	300	600
Gas flow rate, acfm	33,000	48,000	82,000
Temperature, °F	70	70	70
Moisture content, %	2	2	2
Dust loading			
Inlet, gr/scf	10	10	10
Outlet, gr/scf	0.0222	0.0222	0.0222
Inlet, lb/h	2830	4110	7030
Outlet, lb/h	62	90	155
Cleaning efficiency, %	99.78	99.78	99.78

Because of their layouts, the plants that have capacities of 200 tons/h and 300 tons/h each require two separate fabric filters, whereas the largest plant that has a capacity of 600 tons/h requires three fabric filters.

Design specifications for each of the fabric filters are as follows:[40]

Type: pulsed jet, negative pressure

Filter velocity: 6.5 ft/min

Filter media: polypropylene felt bags

Construction: carbon steel housings

Collection efficiency: 99.78 percent

Pressure drop: 17 in. H_2O

Control Costs--Table 2-26 presents capital and annual costs of fabric filter systems serving the model plants. The total

Table 2-26. CAPITAL AND ANNUAL COSTS OF FABRIC FILTER SYSTEMS FOR MODEL SIZING AND TRANSFER OPERATIONS[40]

	Plant size, tons/h		
	200	300	600
Exhaust flow rate, acfm[a]	16,500	24,500	27,300
Number of units	2	2	2
CAPITAL COST			
Equipment	$ 29,300	$ 38,700	$ 42,600
Direct	76,800	101,300	111,900
Indirect	16,000	19,200	21,300
Capital	92,800	120,500	133,200
Total capital cost[b,c]	$186,000	$241,000	$400,000
ANNUAL COST			
Direct operating[d]	$ 11,700	$ 15,500	$ 17,800
Fixed	16,000	20,700	22,900
Total annual cost per unit	$ 27,700	$ 36,200	$ 40,700
Total annual cost	$ 55,400	$ 72,400	$122,000
COST-EFFECTIVENESS			
¢/lb pollutant removed	1.2	1.1	1.1

[a] Flow rate for individual sources being controlled.

[b] Capital cost of each unit multiplied by number of units.

[c] All costs escalated to December, 1977, using Chemical Engineering Plant Index.

[d] Based on 2200 hours of operation per year at 75 percent of rated capacity.

capital costs of retrofitting the fabric filter systems on the 200-tons/h, 300-tons/h, and 600-tons/h model plants are $186,000, $241,000, and $400,000 respectively. The equipment cost represents approximately 32 percent of the total capital costs. The capital cost, expressed as cost per unit volume, ranges from $4.88 to 5.64 per acfm for the large to the small plant, as a result of economy of scale.

The annual costs are estimated to be $55,400, $72,400, and $122,000 for the small, medium, and large model plants, respectively. These costs are based on 2200 hours of operation per year at 75 percent of the rated capacity. The direct operating costs represent about 43 percent of the total annual costs.

Cost-effectiveness--Cost-effectiveness does not differ significantly for each plant size because annual costs and the amount of pollutant removed are fairly proportional to exhaust volume. The cost is computed at about 1.1¢/lb of pollutant removed. Figure 2-19 illustrates the variation of cost-effectiveness with plant size. This illustration indicates that cost-effectiveness will improve at some point between a 200- to 300-tons/h plant. These cost estimates are applied to the model plants only, however, and cannot be used for general estimating. For plants of less than 200 tons/h cost could exceed 1.2¢/lb of pollutant removed.

Wet Dust-Suppression System--

Model plant parameters--Dust emissions at critical dust-producing points in the process flow are controlled by a wet dust-suppression system.

The wet dust-suppression systems applied to each model plant include the following auxiliary items:[40]

Shelter house for pump metering mechanism

Water filter and flush system

System winterization

Automatic spray at truck dump station.

Control costs--Table 2-27 presents capital and annual costs of the wet dust-suppression system for each model. Capital costs for the 200-tons/h, 300-tons/h, and 600-tons/h model plants are estimated at $71,000, $73,600, and $80,400, respectively. The equipment costs represent about 35 percent of the total capital costs. Capital costs do not increase rapidly with size because some of the equipment is identical for each model plant. Hence, the cost per unit size decreases rapidly for wet dust-suppression of a fugitive dust source.

Annual costs are estimated at $15,000, $16,000, and $20,100 for the 200-tons/h, 300-tons/h, and 600-tons/h model plants, respectively. These estimates are based on 1650 hours of operation per year. As shown in Table 2-27, the direct operating costs vary more in proportion to the plant size than do the fixed costs.

The cost-effectiveness of wet dust-suppression systems increases rapidly with plant size. The actual cost-effectiveness estimate cannot be determined because no estimate of emissions is available.

Table 2-27. CAPITAL AND ANNUAL COSTS OF WET DUST-SUPPRESSION SYSTEMS FOR CRUSHERS, SCREENS, TRANSFER POINTS, AND CRUSHER FEEDS[40]

	Plant size, tons/h		
	200	300	600
CAPITAL COST			
Equipment[a]	$24,200	$26,300	$28,600
Total direct cost	62,900	65,200	71,600
Total indirect cost	8,100	8,400	8,800
Total capital cost	$71,000	$73,600	$80,400
ANNUAL COST[b]			
Direct operating	$ 2,900	$ 4,100	$ 6,400
Fixed	12,100	12,700	13,700
Total annual cost	$15,000	$16,800	$20,100

[a] Includes dust-suppression equipment, water filter and flush, high-pressure truck-dump station, shelter house, and equipment winterization.

[b] Based on 1650 hours of operation per year.

Combined Fabric Filtration and Wet Dust-Suppression--

Effective dust control can be achieved at some plants by applying a combination of fabric filtration and wet dust-suppression systems. This strategy probably is more economical than complete dry collection because fabric filter systems are much more expensive. A combined system would provide greater emission reduction than complete wet dust-suppression. The cost-effectiveness would be much greater than for fabric filter systems alone.

Model plant parameters--Fabric filters of the type previously discussed are applied at points where fine particle size emissions occur in the model plants, primarily at secondary and tertiary crushers and screens. Wet dust-suppression techniques are used at primary crushers, screens, transfer points, and crusher feeds, where particle sizes are much larger and moisture content is higher.

Fabric filter costs are based on estimated exhaust gas flow rates obtained from Reference 41 for each model plant.

Control costs--Table 2-28 presents capital and annual costs for control by the separate and combined systems. The total capital costs of the combined system for the 200-tons/h, 300-ton/h, and 600-tons/h model plants are estimated to be $135,000, $159,000, and $195,000, respectively. The corresponding annual costs are estimated to be $35,500, $43,400, and $55,500. The capital and annual costs are considerably lower for the combined system than for a complete fabric filter system. (See Table 2-26.) The costs increase less rapidly with plant size than with the complete fabric filter control.

Cost-effectiveness--Because no estimate can be made of the emission reduction achieved by the wet dust-suppression system, its cost-effectiveness cannot be computed. Assuming a proportional increase of emissions with plant size, the cost-effectiveness would be in ratios of about 17:14:9 for the small, medium, and large plants, respectively.

Table 2-28. CAPITAL AND ANNUAL COSTS OF COMBINATION FABRIC FILTERS AND WET DUST-SUPPRESSION SYSTEMS FOR CRUSHERS, SCREENS, TRANSFER POINTS, AND CRUSHER FEEDS[39]

	Plant size, tons/h		
	200	300	600
A. Fabric filter			
Exhaust flow rate, acfm	11,000	16,500	25,000
Number of units	1	1	1
CAPITAL COST			
Equipment	$ 21,300	$ 28,800	$ 40,000
Direct	56,500	76,800	104,500
Indirect	13,900	15,000	19,200
Total capital cost	$ 70,400	$ 92,800	$124,000
ANNUAL COST			
Direct operating[a]	$ 8,500	$ 11,900	$ 15,500
Fixed	12,200	15,000	21,300
Total annual costs	$ 20,700	$ 26,900	$ 36,800
B. Wet dust suppression			
CAPITAL COST			
Equipment	$ 21,800	$ 23,700	$ 25,700
Direct	56,600	58,700	64,400
Indirect	7,300	7,600	7,900
Total capital costs	$ 63,900	$ 66,300	$ 71,300
ANNUAL COST			
Direct operating[b]	$ 2,900	$ 4,100	$ 6,400
Fixed	10,900	11,400	12,300
Total annual costs	13,800	15,500	18,700
Total combined capital costs	$134,000	$159,000	$195,000

[a] Based on 2200 hours of operation per year at 75 percent of rated capacity.

[b] Based on 1650 hours of operation per year.

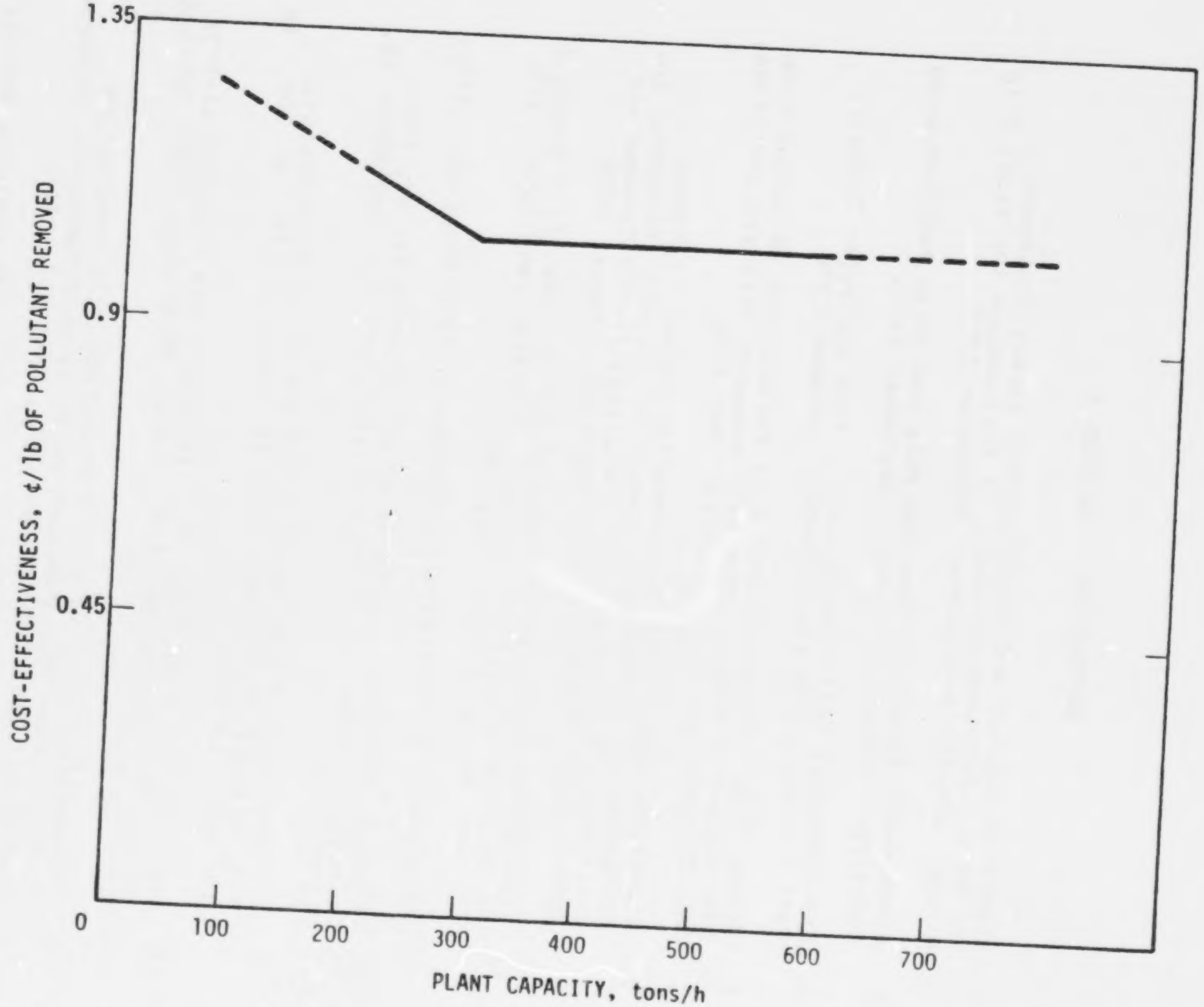


Figure 2-19. Cost-effectiveness of fabric filter systems for model processes.[38]

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SECTION 3

OPERATION AND MAINTENANCE OF PARTICULATE CONTROL DEVICES

As with other complex equipment, the successful functioning of pollution control systems depends not only on sound design and proper installation, but also on proper operation. Ideally, the plant personnel who use and maintain the equipment will understand the engineering principles on which the control system is based and will apply this knowledge both in routine operation/maintenance and in emergency situations.

3.1 OPERATION AND MAINTENANCE OF ELECTROSTATIC PRECIPITATORS

This section deals specifically with electrostatic precipitator applications on recovery furnaces and bark/fossil fuel-fired boilers used at kraft pulp mills.

Problems with electrostatic precipitators can arise when the precipitator is brought on line and also after extended operation. Since the possible causes of poor precipitator performance are diverse, it is impractical to outline a single procedure for determining the nature of a specific problem. When a malfunction occurs, the operator must depend on his theoretical understanding of the equipment, backed by his practical experience. This section of the report, therefore, provides background information on precipitator operation, together with detailed maintenance and trouble-shooting procedures for the major component categories.

Presently, two methods are used in recovery boiler operations to concentrate the black liquor: 1) the more prevalent conventional method (direct-contact evaporation) and 2) the low-odor method (indirect contact evaporation). The nature of the particulate was shown previously in Section 2.3.3, Table 2-12.[1] Since the basic precipitator functions are those of charging and collection of particles, the components and controls associated with the transformer-rectifier (T-R) sets, vibrators, and rappers constitute the heart of the electrostatic precipitator system. The more tenacious dust from the low-odor operation can be removed from the precipitator plate by vibrating with air vibrators. The collected dust from the conventional process is removed by rapping; the trend, however, is to also use air vibrators on such applications.

The procedures presented here are those suggested by Research-Cottrell, Inc. Although other manufacturers might recommend different procedures as dictated by details of system design, most of the major components, and therefore the operating procedures, are similar. Where it is possible, the recommended practices are interpreted in terms of their effects on equipment performance.

3.1.1 Background on Precipitator Operation

Electrostatic precipitation requires two groups of equipment: 1) the precipitation chamber, in which the suspended particles are electrified and removed from the gas, and 2) the high-voltage transformer and rectifier, which function to create the strong electrical field in the chamber.

The chamber consists of an outside shell (precipitator shell) made of metal or tile. Suspended within the shell are grounded steel plates (collecting electrodes) connected to the grounded steel framework of the supporting structure and to an earth-driven ground. Suspended between the plates are wires (discharge electrodes) insulated from ground, which are negatively charged at voltages ranging from 20,000 to 105,000 volts. The great difference in voltage of the wires and the collecting plates sets up a powerful electrical field between them, which imparts a negative charge to the solid particles suspended in the gas stream. Understanding of this phenomenon requires some knowledge of electricity and chemistry; for practical purposes it is enough to know that the particles become electrically charged. The negatively charged particles are attracted to the collecting plates, which are at ground potential. The particles cling to the collecting plate and become electrically inert.

The gas that enters the precipitator laden with particles is channeled through the precipitator outlet, while the dust collected in the hopper or drag bottom is removed via an ash handling system.

It should be noted that reentrainment can be a problem in the conventional process. The collected dust from a conventional process falls into a wet bottom. The dust from the low-odor process falls into a dry drag bottom. The cleaning mechanism can travel in a transverse or longitudinal direction. Removal of the collected dust (principally carbon, sand, and fly-ash) from bark-fired and combination-fired boilers is best achieved by rapping the plates and collecting the ash in trough or pyramidal hoppers.

Figure 3-1 illustrates the major components of a kraft pulp mill precipitator with tophousing (as opposed to insulator compartments). The dust collecting and removal system will vary depending on the application. Appendix B-1 presents a more detailed explanation of precipitator operations including subsystems and components such as transformer-rectifiers, rappers, vibrators, the upper precipitator, discharge wires, collecting plates, and the lower precipitator. The following section describes the fundamental operational procedures necessary for routine operation.

3.1.2 Precipitator Startup and Shutdown Procedures

Operation of an electrostatic precipitator involves high voltage, which is dangerous to life. Although all practical safety measures are incorporated into the unit, extreme caution should be exercised at all times. An electrostatic precipitator is, in effect, a large capacitor which, when de-energized, can retain dangerous electric charges. Therefore, grounding mechanisms provided at each access point should be used before entering the precipitator.

Preoperation Checklist--

Before placing the equipment in operation, plant personnel should perform a thorough check and visually inspect the system components in accordance with recommendations of the manufacturer. A complete checklist of items is presented in Appendix B-2. Some of the major items that should be checked are summarized below:

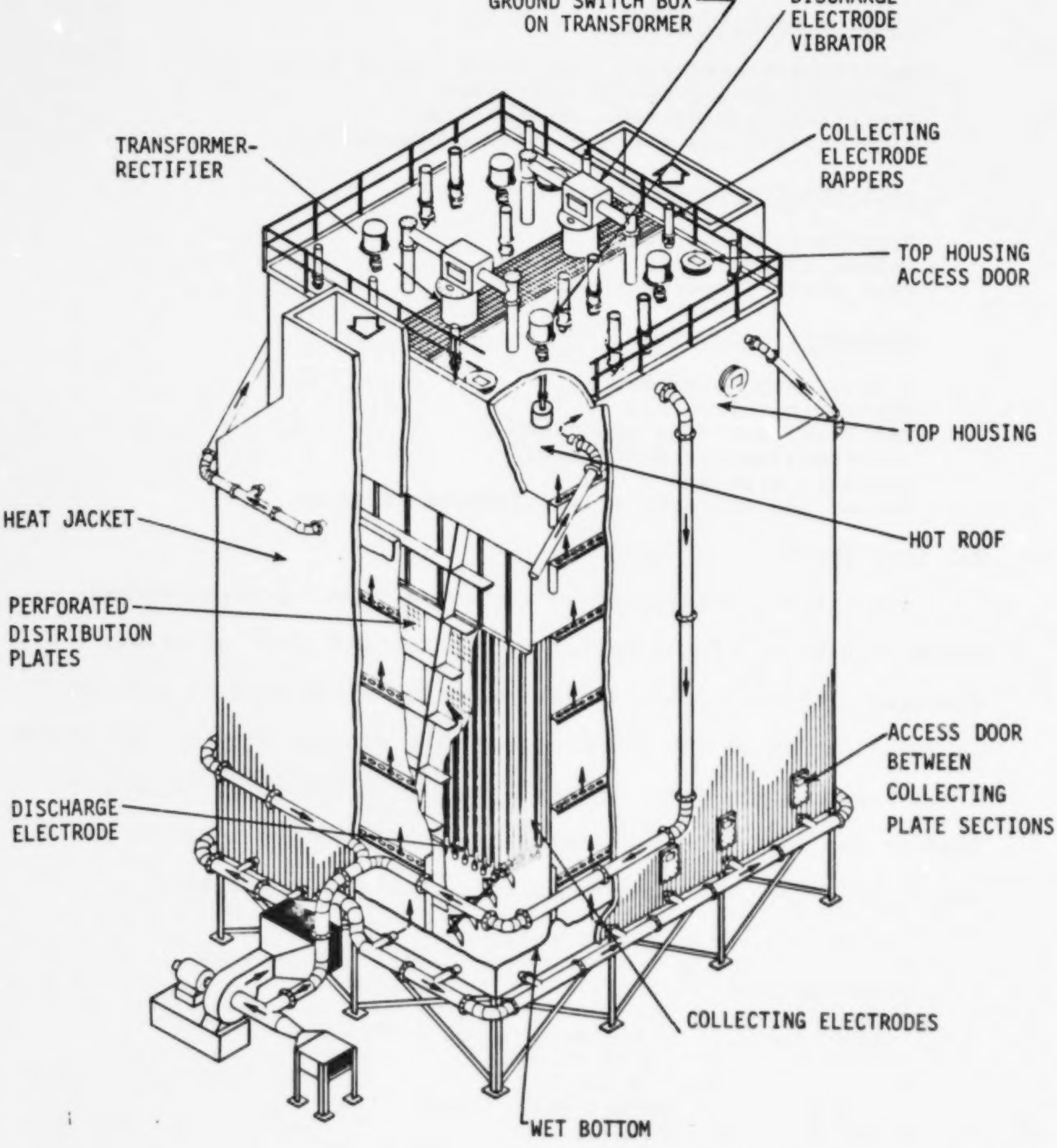

GROUND SWITCH BOX ON TRANSFORMER
DISCHARGE ELECTRODE VIBRATOR
TRANSFORMER-RECTIFIER
COLLECTING ELECTRODE RAPPERS
TOP HOUSING ACCESS DOOR
TOP HOUSING
HEAT JACKET
HOT ROOF
PERFORATED DISTRIBUTION PLATES
ACCESS DOOR BETWEEN COLLECTING PLATE SECTIONS
DISCHARGE ELECTRODE
COLLECTING ELECTRODES
WET BOTTOM

Figure 3-1. Wet bottom electrostatic precipitator with heat jacket.

Control unit

Proper connections to controls

Silicon rectifier unit

Rectifier-transformer insulating liquid level
Rectifier ground switch operation
Rectifier high-voltage connections
High-voltage bus transfer switch operation

High-tension connection

High-tension bus duct
Proper installation
Vent ports properly installed

Equipment grounding

Precipitator grounded
Transformer grounded
Rectifier controls grounded
High-tension guard grounded
Conduits grounded
Rapper and vibrator ground jumpers in place

Air Load Test--

After the precipitator is inspected (i.e., preoperational check adjustment of the rectifier control and check of safety features), the air load test is performed. Air load is defined as energization of the precipitator with minimum flow of air (stack draft) through the precipitator. Before introduction of an air load or gas load (i.e., entrance of dust-laden gas into the precipitator), the following components should be energized:

Collecting plate vibrator-rappers
Perforated distribution plate rappers (if present)
High-tension discharge electrode vibrators
Bushing heaters; housing/compartments
Hopper heaters; vibrators; level indicators
Transformer rectifier (T-R)
Rectifier control units
Ventilation and forced-draft fans
Dust-conveying system

The purpose of the air load test is to establish reference readings for future operations, to check operation of electrical equipment, and to detect any improper wire clearances or grounds not detected during preoperation inspection. Air load data are taken with the internal metal surfaces clean. The data consist of current-voltage characteristics at intervals of roughly 10 percent of the T-R milliamp rating, gas flow rate, gas temperature, and relative humidity.

For an air load test the precipitator is energized on manual control. The electrical characteristics of a precipitator are such that no sparking should occur. If sparking does occur, an internal inspection must be made to determine the cause. Usually, the causes are close electrical clearances and foreign matter, such as baling wire, that has been left inside the precipitator.

After the precipitator has been in operation for some time, it may be necessary to shut it down to perform an internal inspection. At such times it is of interest to take air load data for comparison with the original readings.

Gas Load Test--

The operation of a precipitator on gas load differs considerably from operation on air load with respect to voltage and current relationships. High current and low voltage characterize the air load test, whereas low current and high voltage characterize the gas load test. These relationships govern operation of the precipitator and the final setting of the electrical equipment.

In general, optimum precipitator efficiencies are obtained when the dc voltage applied to the precipitator is at the threshold of sparking. The spark rate at this point will be on the order of 50 to 150 sparks per minute and may be controlled at this level with automatic control.

Shutdown Procedure--

To shut down the precipitator, the operator opens the control circuit start/stop switch and then opens the main circuit breaker. Before entering the system, the operator should follow all safety procedures. Proper grounding of all precipitator parts is important. The key interlock system prevents access to the interior of each T-R ground switch enclosure until the individual set is de-energized and the ground connections are made. This system prevents access to the interior of the precipitator, including top housing or insulator compartments, precipitator roof doors, side doors, and hopper doors, until the T-R's of each precipitator are de-energized and ground connections are made. Purging the system with ambient air may also be desirable from the standpoint of plant personnel who must inspect the internal parts of the precipitator.

3.1.3 Inspection and Maintenance During Normal Operation

Appendix B-3 consists of detailed directions for plant personnel who are assigned responsibility for inspection and maintenance of precipitator systems. These instructions, abstracted from Research-Cottrell's suggested operation and maintenance procedures, are representative of the level of inspection and maintenance required for successful precipitator operation with minimum downtime. Although electrical portions of a precipitator require very little maintenance, the items enumerated in Appendix B-3 should be attended regularly if the equipment is to give optimum service. It is considered good practice to assign one plant operator on each shift the task of checking and recording data on electrical equipment at the start of the shift.

The cycle or inspection and maintenance during normal operation includes the following components:

T-R sets and associated equipment and controls
Transformer enclosure
Pipe and guard
Vibrators
Plate rappers
Top housing
Insulator compartments
Upper high tension frame
Discharge wires
Collecting plates
Lower precipitator steadying frame
Dust collection point (dry or wet bottom)
Hoppers and screw conveyors
Precipitator shell.

Maintenance Schedule and Troubleshooting--

Appendix B-4 also presents a detailed list of maintenance procedures that should be performed on a daily, weekly, monthly, quarterly, semi-annual, and annual basis. These procedures typify the level of effort required to maintain optimum operation. For example, the annual inspection covers the following conditions and subsystems:

Table 3-1. COMPARISON OF DESIGN AND OPERATIONAL FEATURES OF UTILITY AND KRAFT PULP MILL ELECTROSTATIC PRECIPITATORS

Items	Utility boiler	Recovery furnace	Bark/fossil-fuel boiler
Lubrication:			
- Screw bearings	None	Yes	50% screws 50% pyramidal hopper
- General	None	Drag conveyor bearing, speed reducers, flexible couplings	None
Corrosion from air inleakage	Mild	Severe	Mild
Corrosion environment	SO_3 (mild)	SO_3 (at low temperature) sometimes Cl	SO_3 (mild)
Explosive environment	None (rare)	Rare	Explosion rare; hopper fires due to high carbon possible
Purge air	Air	Air	Air
Explosions from air inleakage	None (rare)	Rare	Explosions rare; fire possible if leakage is near unburned carbon accumulations
Precipitator material selection	Mild steel	Generally mild steel with heat jacket to maintain high temp. and minimize corrosion	Mild steel
Dust buildup	Normal rapping	Dust is very tenacious; air vibrators are normally used	Normal rapping
Dust removal	Pyramidal hoppers; vacuum discharge	Wet bottom or drag conveyor	Trough hoppers or pyramidal hoppers
Insulation	Required to minimize temperature drop	Required to minimize cold spots, and thus reduce corrosion significantly, especially around access doors	Required to minimize cold spots and reduce corrosion
Heat jacket	None	Maintain high shell temp. to reduce corrosion	None
Material selection of special items	Mild steel	Grating often is galvanized to protect against salt attack; special zinc-based paints are often used on T-R's bus duct, etc. to resist salt attack. FRP is used when temp. are not high and corrosion is a problem	Mild Steel

(continued)

Table 3-1 (continued)

Items	Utility boiler	Recovery furnace	Bark/fossil-fuel boiler
T-R set application	Uniform design approach	Small T-R's on inlet fields due to fine fume and current suppression. Larger T-R's on center outlet	Uniform design approach
Dust buildup	Minimal problem	Flues and horizontal surfaces must be designed for velocities to eliminate buildup. Vibrators and soot blowers are often needed on vanes, flue floors, hopper walls, beams, etc.	Minimal problem

N/A - Not applicable

Dust accumulation
Discharge wires
Alignment of plates and wires
High-tension and plate vibrator-rappers
High-tension frame support bushing
High-voltage electrical control cabinet
T-R sets
Dry/wet bottom
Hoppers
Screw conveyor

Table B-3-1, Appendix B-4, lists troubleshooting measures recommended by precipitator manufacturers for determining the most probable cause of precipitator problems; Table B-3-2 gives an example of the frequency of failure and time to repair various components of a typical industrial precipitator.

3.1.4 Operation and Maintenance Problems Specific to Kraft Pulp Mills

The information presented in the preceding sections pertains to most precipitator applications. Table 3-1 illustrates the important differences between utility and kraft pulp mill precipitators, i.e., those controlling recovery furnaces and bark-fired and combination-fired boilers. The most common malfunctions associated with electrostatic precipitators applied to recovery furnaces stem from corrosion and failure of rappers. Other problems result from drag bottom conveyors, plugging of the inlet distribution plate, buildup on ladder vanes, and "snowing" (intermittent puffing of recovery furnace stacks).[2]

Corrosion--

Corrosion is more severe with conventional than with low-odor recovery furnace operations, mainly because of the lower operating gas temperatures in conventional recovery furnaces. It is essential that both the precipitator inlet and outlet flues be insulated, as well as the shell. At flue gas temperatures below 300°F, local cold spots may cause condensation and create severe corrosion. A heated steam or air coil system provides a means of keeping all internal shell wall surfaces above the dew point of vapors in the gas being cleaned and thus preventing condensation of corrosive chemicals anywhere on the walls. Operating the wet bottom at extremely low liquor levels leads to inleakage of cold outside air at the agitator hubs, which causes corrosion of the wet pan. Maintaining the proper liquor level can eliminate this problem.

Rapper Failure--

Dust is removed from the collecting and discharge electrodes by means of air or electrically operated vibrators/rappers. Although intensities and frequencies depend on the specific installation, plate and wire vibrators and rappers are usually in continuous operation. The importance of the vibrating/rapping system cannot be overemphasized, since any failures within the system will cause loss of power input to the precipitator and a reduction in precipitator performance.

Drag Bottom Conveyors--

Dust is conveyed from the electrostatic precipitator dust chamber to the salt-cake mix tank either concurrently to the gas flow (longitudinal drag bottom) or perpendicularly to the gas flow (transverse drag bottom). The latter method lessens the possibility of gas sneakage, which is typically associated with the longitudinal drag bottom. Systems that convey the dust perpendicular to the gas flow must be broken into at least two sections. One conveyor mechanism should serve the inlet field separately and should be designed to accommodate the bulk of the dust.

Plugging of Inlet Distribution Plate and Ladder Vanes--

Plugging is a function of operating temperature. Most problems are eliminated when operating temperature exceeds 325°F. Dust accumulations on the inlet turning vanes cause some maldistribution of gas flow patterns. Any change in design to eliminate the necessity of these structures would improve the operation, maintenance, and performance of the precipitator.

"Snowing"--

The principal cause of "snowing" is dust-laden gases bypassing the treatment zones. In wet bottom units the gases pass through gaps between the baffle plates and tile shell. Other causes of "snowing" can be a sudden release of particles accumulated in the ductwork, too heavy vibrating or rapping, too high gas velocities, and an increase in load on the precipitator caused by an increase in throughput of the recovery furnace. Use of a low-energy scrubber following an electrostatic precipitator helps to eliminate "snowing."

A 1974 survey by the TC-1 committee of the Air Pollution Control Association (APCA) details operational problems of 36 paper mills reporting on 49 precipitators.[3] Respondents indicated that rapper/vibrators presented the largest maintenance problem followed by discharge electrodes, collecting plates, insulators and dust removal system. Table 3-2 compares maintenance problems for utility, metallurgical, and paper mill applications from the above study. Paper mill respondents reported maintenance to be a greater problem in general, than did utilities or respondents from metallurgical processes.

The incidence of maintenance problems as reported by paper mills corresponds well to the design and operational information presented in Table 3-1 on kraft recovery boilers.

Little information is available concerning malfunctions associated with bark-fired combination-fired boilers. One possible source of problems with such an application is the potential for fire caused by buildup of "char" on precipitator walls and especially in the hoppers. The fire hazard can be minimized by installing trough type hoppers for continuous removal of dust. Also the elimination of all inleakage will decrease the availability of air for combustion.

3.2 MAINTENANCE AND OPERATION OF MECHANICAL COLLECTORS SERVICING BARK/FOSSIL-FUEL BOILERS

Mechanical cyclone collectors are used as primary collectors on wood-fired boilers or as first-stage collectors for coal-fired units.[4]

Mechanical collectors separate dust from a gas stream by a combination of centrifugal, gravitational, and inertial forces. Cyclones, the most common of the mechanical collectors, make use of most of these mechanical forces. Rotational action creates a centrifugal force that drives the suspended particles to the

Table 3-2. MAJOR MAINTENANCE PROBLEMS WITH UTILITY, METALLURGICAL, AND PAPER MILL PRECIPITATORS[a]

Industry	Discharge electrodes, %	Rapper/ vibrator, %	Collecting plates, %	Removal system, %	Insulators, %
Utilities[b]	35.2	5.7	13.6	31.8	1.1
Metallurgical[c]	25.0	33.3	22.2	19.4	25.0
Paper and pulp[d]	20.4	34.7	16.3	4.1	6.1

[a] Users' opinion of which category constitutes the major problem area. (Reference 3).

[b] Based on 63 utilities reporting on 88 precipitators.

[c] Based on 22 metallurgical processes reporting on 36 precipitators.

[d] Based on 36 paper mills reporting on 49 precipitators.

wall of the cylinder. The gas and the dust begin a downward spiral towards the cone and finally to the dust discharge; this outside downward spiral is the main vortex. As the main vortex spirals downward, a quantity of gas is drawn radially inward to feed a smaller inner vortex spiralling upwards to the clean gas discharge tube.

3.2.1 Startup/Shutdown

Check blower rotation.

Make sure that all inspection doors, connections, etc., are closed.

Turn on blower and check current, pressure drop, and system pressure drop.

Check inlet and outlet gas and dust flows. To shut the system down, pass clean air through the system to permit the cyclone to dry and empty out, then turn off blower.

Clean out the hoppers to prevent plugging.

3.2.2 Normal Operation[5]

At least once a shift, the pressure drop across the collector should be recorded. Normally, the pressure drop across the cyclone is greater than that of any other component in the system. If the pressure drop is measured across the system and if resistance to gas flow occurs somewhere other than in the cyclone, the reduction of gas flow could reduce the pressure drop across the cyclone. It is advisable to install a manometer across the fan and record static pressure readings from the time of startup. These are used as a reference for subsequent operations.

Every collector should be equipped with a test tap at the inlet and outlet ducts to monitor pressure drop across the unit. The dust discharge hopper should always be equipped with a pokehole on the top surface. The ash removal system is operated frequently enough to ensure that the hopper never fills enough to reach the bottom of the collecting tube. If there is any doubt about this, install a bin level gauge with an alarm. Leakage will reduce efficiency.

3.2.3 Maintenance

Leakage into the cyclone or dust discharge hopper is difficult to detect on a negative pressure system. When a rotary valve acts as the seal, the wear plate should be self-adjusting so that as it wears down (metal on metal) it always maintains a seal. When a counterweighted or flap valve acts as the seal, the maintenance crew must check for buildup in the valve seat or flapper plate.

Additional checks should be made on fan bearings, leakage around gaskets and valves, and general wear and tear on the system.

3.2.4 Operation and Maintenance Problems Specific to Cyclones

Literature regarding bark boiler operations is so scarce that most of the design considerations for cyclones are presented in general terms. Where information specific to bark boilers is available, it is included together with some typical problems of cyclone operation.

The action inside a cyclone is always dynamic; the dust particles are either gouging and channeling or sticking to a surface and then to each other, all of which can cause erosion and dust buildup.

Erosion--

Particles with high specific gravity, and in high concentration, moving at high velocities and impinging on a surface will erode the cyclone wall. With light inlet dust loadings, erosion is prevalent in the cone; with heavier inlet dust loadings, erosion occurs in the cylinder of the cyclone. Improper cyclone design or poor operating conditions tend to concentrate the fast-moving dust and increase erosion.[6] The areas most prone to erosion damage are weld seams, mismatched flange seams, the bottom of the cone, and the wall opposite the inlet. Erosion can be eliminated by installing removable wear plates of abrasion-resistant metal or rubber. Erosion can be reduced by increasing the diameter of the cyclone body without increasing the diameter of the gas outlet tube. This can lead to an increase in pressure drop.[7] The use of troweled or cast refractory linings is the best method of combating erosion in cyclones.

Dust Buildup--

Plugging of the cyclone reduces efficiency and increases pressure drop, and may increase erosion. Dust buildup usually occurs at the dust outlet or at the cyclone wall. Dust outlets become plugged by foreign matter or by hoppers overfilling. Buildup on the cyclone wall is a function of particle size and caking characteristics. The presence of fine dust such as that from salt emissions from bark boilers and moisture condensing on the walls tend to increase dust buildup. Maintaining gas velocities above 50 ft/s will minimize buildup on the cyclone wall by the scouring action of the gas.[7]

3.3 OPERATION AND MAINTENANCE OF WET SCRUBBERS

In the kraft pulp mill industry wet scrubbers are used on sludge lime kilns, smelt dissolving tanks, and bark/fossil-fuel boilers.

Historically, dry mechanical collectors and low-energy scrubbers were used to control dust emissions from the crushed stone industry. Presently, the controls used most commonly are fabric filters, followed in order by wet suppression techniques, a combination of wet dust suppression and fabric filters, and mechanical collectors and/or wet scrubbers.[8] In stone crushing operations the most commonly used wet scrubber is the venturi. For this reason, the following commentary is restricted to gas atomized spray type scrubbers.

3.3.1 Description

Gas atomized spray type scrubbers utilize a moving gas stream to atomize liquid into drops and then accelerate the drops. Acceleration of the gas provides impaction forces as well as intimate contact with the liquid stream. Within this category many differences in design and operation may be noted with respect to the following items: method of adjusting pressure drop (the difference being that between the true venturi and the annular orifice); the method of moisture elimination (centrifugal moisture elimination, as with spinning vanes or multi centrifugals). In any event, most gas atomized spray scrubbers incorporate the converging and diverging section typical of the venturi throat.

The collection efficiency of a venturi scrubber is dependent upon the pressure drop across the scrubber. Pressure drop in turn is dependent upon operation at close to design flow conditions or provision of an adjustable venturi throat. The low flue gas temperature and high moisture content of the flue gases from a venturi scrubber may lead to undesirable plume rise and plume visibility. The scrubbing medium may affect the odorous emissions, and fresh water rather than contaminated condensate should be used to minimize odorous emissions. Venturi scrubbers that incorporate variable throat designs provide a high level of efficiency under varying inlet conditions when operated within their design capacity.

A typical flooded-disc scrubber system for particulate collection consists of a flooded-disc scrubber, a mist eliminator with sump, two recirculation pumps, and one booster fan or ID fan. A gas prequencher is sometimes required for treating high-temperature gas.

The flooded disc scrubber, shown in Figure 3-2, is composed of a disc in the tapered throat section of a vertical hollow

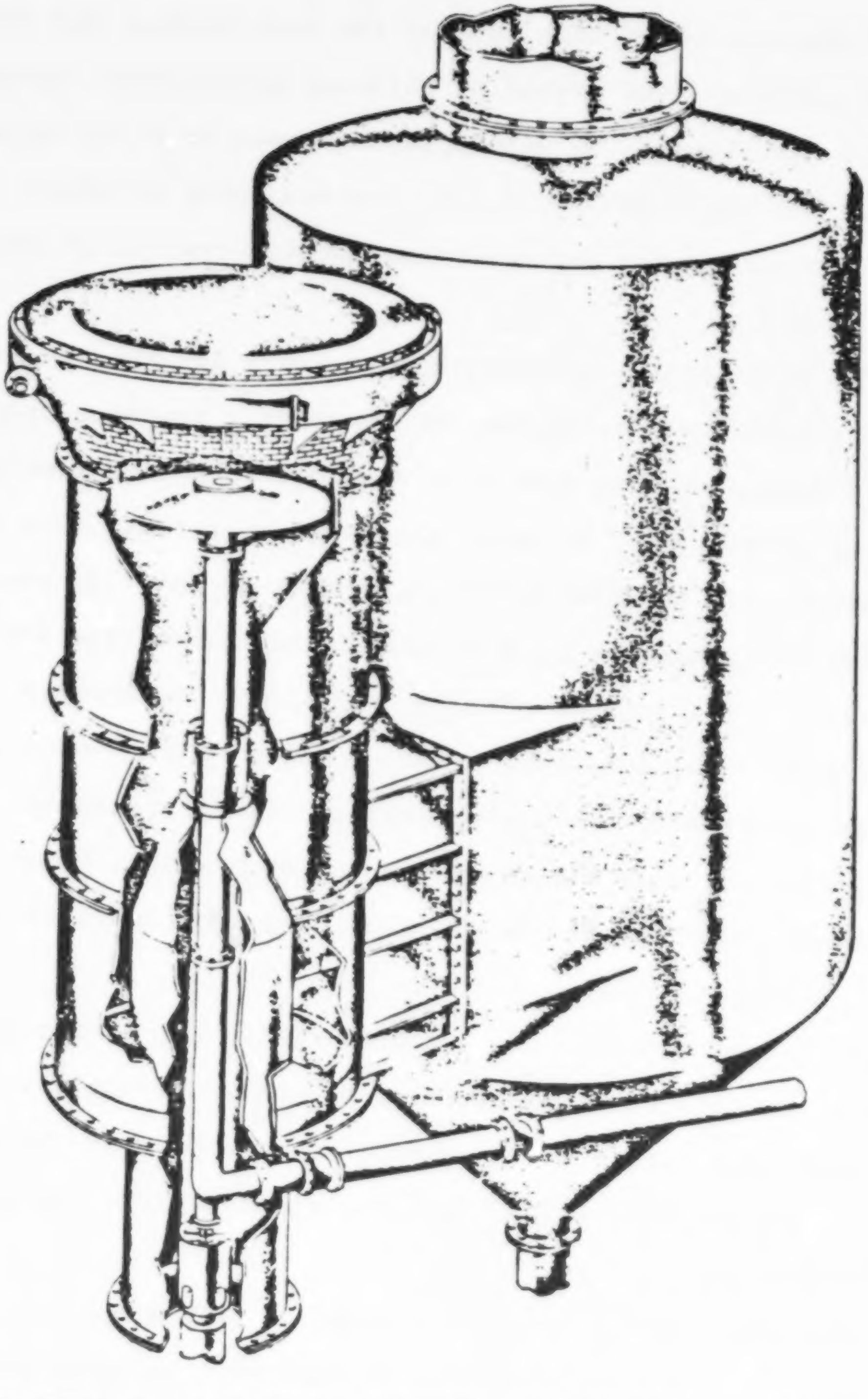


Figure 3-2. Research-Cottrell flooded disc scrubber.

cylinder. The disc is supported by a pipe, and an open annulus is formed between the wall and the disc. As the gas flows through the annulus and the scrubbing water is ejected simultaneously across the disc face, atomization takes place at the annulus. The millions of fine water droplets that are created are used for particle capture in the gas stream. The particulate collection efficiency of the scrubber depends on the degree of atomization, which is indicated by the pressure drop across the scrubber. Pressure drop across the scrubber can be regulated by controlling the vertical displacement of the disc in the venturi throat section automatically or manually. To provide the same collection efficiency, the pressure drop must be higher in collecting fine particles than in collecting coarse ones. Given particles of the same size, the pressure drop must be higher to achieve relatively higher collection efficiency.

The purpose of the mist eliminator is to separate the dust-laden water droplets from the gas stream by centrifugal force. The separated dust-laden water flows by gravity to a sump for recirculation to the scrubber. The solids content of the slurry that is recirculated by the recycle pump gradually increases. For control of the solids content level in the slurry, a purge stream from the discharge of the recycle pump is pumped out of the system, as indicated by the slurry density control. During system operation, some water is lost from the sump with the purged slurry and some is vaporized as the hot gas comes in contact with the scrubbing liquor. To compensate for the lost water, a makeup water stream is pumped to the recirculation sump, as indicated by the slurry level control.

All of the variables are controlled within the high and low limits. An alarm signals any operating condition beyond the control limits to warn the operator of an abnormal condition. The major controls and alarms in the scrubber system include pressure drop across the scrubber, slurry density in the scrubber, slurry level of the recirculation sump, and slurry flow rate to the scrubber. For the purpose of safety, the scrubber system should incorporate interlock circuits to protect the equipment in the event of an emergency.

3.3.2 Operation

Preoperation--

Before the system startup, all major items of equipment, connecting pipes, and auxiliaries must be inspected, cleaned, and tested. A new system should be checked for leaks and instabilities by an air test for the fans and ductworks and a hydraulic test for pipings and valves. In addition, a water test should be performed to ensure that equipment, instruments, and control/safety systems are working properly. The items that should be checked in preoperation tests are summarized below:

- FD/ID fan

  Electrical controls, fan bearing coolant system, alignment, lubrication, vibration sensors, bearing temperature sensors.

- Pumps

  Belt tension, pump rotation, pump alignment, lubrication, seal water, packing, pressure gauge, suction and discharge valves, motor bearing temperature, hydraulic system (for flooded-disc control pump).

- Control Systems

  Flue gas bypass, pressure drop, makeup water rate, recirculation sump level, slurry density, slurry purge rate.

- Safety Systems (interlocks and alarms)

  High flue gas pressure, low level in sump, high and low density.

- Utilities

  Electric power, instrumentation air, process water, process return water.

Startup--

To start up a system for the actual operation or for a water test operation, one must follow the procedure described in the system designer's operating manual. Following are several steps in the startup of a new scrubber system:

1. Close all drain valves.
2. Turn on circuit breakers for all instruments and electric valves.
3. Set all monitoring instruments at zero reading.
4. Startup the service water system and raise the water level in the sump to the designated level.
5. Turn on the recycle pumps circuit breakers and start up the operating and standby pumps.
6. Turn on the circuit breaker for the disc control pump, start up the disc control pump, and adjust the high and low limits of the pressure drop indicator (in venturi scrubbers).

7. Close the flue gas bypass dampers and start the fan.
8. Check the scrubber pressure controller and the system monitoring instruments.

Shutdown--

Following is a general procedure for planned shutdown of a flooded disc scrubber system:

1. Turn the flue gas damper to the bypass position and stop the fan.
2. Close the makeup water and slurry couple valves.
3. Stop the recycle pumps (both operating and standby).
4. Open the drain valves at the slurry pumping lines and flush the lines, gauges, and pumps with water.
5. Stop the disc control pump and leave the disc in the fully raised position.
6. Open the drain line on the pressure gauges to the throat and disc and allow the line to drain.

Normal Operation-

Under normal operating conditions, all of the control parameters should be held within the defined ranges. These include the scrubber pressure drop, recycle pump rate, makeup water rate, slurry density, slurry purge rate, and recirculation sump level.

An abnormal condition is defined as a deviation of the operating condition beyond the normal range. The abnormal condition will be indicated by an alarm. If the operator cannot correct the condition, under certain circumstances an interlock will open the flue gas bypass damper and shut down the scrubber system.

During normal operations the following malfunctions may develop:[5]

1. Pump impeller wear is indicated by a reduction in scrubber recycle flow. Valve or nozzle erosion is indicated by an increase in scrubber recycle flow.
2. A decrease in scrubber bleed flow is associated with line plugging. An increase in bleed flow can indicate a worn valve.
3. An increase in pressure drop can be caused by plugging of packing or by an increase in flow of gas or liquor.
4. An increase in pump discharge pressure at proper flow rate usually indicates line plugging.
5. Fan inlet and outlet pressure readings can be used to check flow as well as damper setting.
6. Dust buildup on fan blades is indicated by an increase in fan vibration.
7. Motor current indicates whether a flow decrease is caused by impeller wear, plugging, or an incorrect flow meter setting. Fan current is synonymous with gas throughput.

The following alarm conditions are associated with the system:

1. Scrubber pressure drop

   An alarm condition may occur because of a malfunctioning pressure drop controller, failure of the disc control pump, jammed disc, or a rapid change of boiler load.

2. Slurry density

   An alarm condition may occur because of a malfunctioning control, a defect in the density control valve, a malfunction in the sump level control, or a change in the makeup water rate.

3. Recirculation sump level

   An alarm condition may occur because of a malfunctioning control or because of high or low level of slurry in the sump.

4. Others

An alarm condition may occur because of plugged lines, closed valves, pump trouble, or fan trouble.

3.3.3 Inspection and Maintenance During Normal Operation

Many of the items on the preoperation checklist should be checked in routine maintenance. This maintenance generally includes unplugging lines, nozzles, pumps, etc.; replacing worn equipment parts, erosion/corrosion prevention liners, and instruments (level indicators, density indicators, etc.); and repairing damaged components when this is practical from the standpoint of labor and materials.

The wet-dry line must be inspected periodically for buildup of solids. Spray nozzles and liquid inlets must be checked to see that they are open and distributing the liquid properly. Corrosion can occur underneath built-up scale. Abrasion is another major problem in most scrubbers with mechanical or centrifugal shaft actuation devices.

Points of possible corrosion and abrasion must be inspected frequently. These include throats, orifices, elbows, and any other high-wear areas. Wear on coatings and metal surfaces should be repaired as needed. Ductwork, dampers, fans, centrifugal pumps, valves, and piping require systematic inspection.

Most fan problems are indicated by a change in vibration. When a fan is inspected, the casing should be opened and the wheel and casing washed. The wheel can be checked for erosion, pitting, and cracking, particularly in weld areas. Many fan problems are caused by lack of proper bearing lubrication. If the fan is equipped with a spray wash system, the piping and nozzles should be thoroughly inspected. Unusual stresses in the fan can tear spray piping loose and cause chipping of the fan wheel.

Centrifugal pumps should be opened periodically and inspected. Pump packing should be replaced during each inspection. The liquid level to the pump gland (packed type) should be checked once per shift to prevent corrosive or erosive damage of the shaft, sleeve, and bearing.

The following checklist, based on problems encountered in scrubber operation, should be followed routinely. Corrections should be in accordance with the manufacturers' recommended procedures.

- Check the scrubber disc in the venturi scrubber to ensure even distribution across the disc surface.
- Check erosion and corrosion of all scrubber internal surfaces. Repair as necessary.
- Clean and descale all scrubber internal surfaces. While descaling, exercise care to prevent damage to the linings.
- Perform maintenance of the hydraulic packing of the scrubber disc.
- Check nozzles for buildup or damage. Repair or replace as necessary.
- Check for solids buildup in blowdown lines. The lines may be cleaned without system shutdown, and a flush connection may be installed to prevent further buildup.
- Check for corrosion, erosion, and leaks in lines having protective liners, which may have deteriorated. Replace liners as required.

- Check operation of mist eliminator. Formation of droplets can be caused by excessive gas flow rate, plugged drains from the moisture eliminator, or condensation in the outlet duct.
- Check pumps for wear, seal water, packing, and smooth operation.
- Check dampers and damper linkages for proper positioning and wear.
- Check fans for lubrication, fan bearing coolant, belt wear and belt tension, and erosion/corrosion of the impeller.
- Inspect all interior surfaces and condition of mist eliminator and sump during major outages.
- Inspect the exterior for leaks in all process and control lines, ductwork, and expansion joints.
- Note the condition of all instruments such as level probes and density probes with regard to solids buildup. It is impractical and usually impossible to remove solids buildup from the probes, which often must be replaced.
- Perform a final check for proper operation of density sensors, pressure drop control, and level elements.
- In the impingement scrubber, check the liquid level control and possible solids deposition in the cone bottom.

Table 3-3 lists general maintenance requirements for venturi scrubbers based on two ranges of pressure drops, and various lining materials and gas characteristics. This table should be useful in the selection of scrubber liners for lime kilns, smelt dissolving tanks, combination bark/fossil-fuel boilers, and various crushed stone processes.

Spare Parts--

The minimum inventory is one of each part for each venturi scrubber. The inventory for a venturi system is given in Table 3-4.[9]

Table 3-3. SCRUBBER MAINTENANCE[9]

Type of liner	Pressure drop				Gas characteristics			Comments
	>30-in. ΔP		<30-in. ΔP					
	Life cycle, yr	Repair time	Life cycle, yr	Repair time	Corrosive	Abrasive	Corrosive and abrasive	
Ceramic								
Silicon carbide	3-4	2 men/ wk	10	2 men/ 1 wk	Poor	Excellent	Good (mildly corrosive)	
Cement	1	2 men/ wk	4	2 men/ 1 wk	Poor	Poor	Good (mildly corrosive)	
Rubber	1	2 men/ 2 wks	5	2 men/ 2 wks	Excellent	Good	Good	For cutting type particles For erosive but not sharp particles.
Rubber	5	2 men/ 2 wks	10	2 men/ 2 wks	Excellent	Good	Good	
Plastic			Indefinite	1 day				Patchable lining
Steels								
Carbon	2-6	Patchable	6	Patchable	Poor	Fair	Fair	Good for chlorides
316	2-6	Patchable	6	Patchable	Excellent	Fair	Fair	Not good on chlorides
304	2-6	Patchable	6	Patchable	Good (arid)	Fair	Good	Except for SO_3^- and Cl^-
Inconel 625	2-6	Patchable	6	Patchable	Good	Good	Good	
Hastoloy	2-6	Patchable	6	Patchable	Excellent	Good	Good	

Table 3-4. SPARE PARTS INVENTORY FOR VENTURI SCRUBBER[9]

Section of the system	Type of parts							
	Motors	Mist eliminator modules	Seals	Bearings	Impeller	Reamers (50% of total)	Packing material	Adjustable throat-damper	None
Scrubber						X	X		
Separator								X	
Fan	X		X	X	X				
Pump(s)	X		X	X	X				
Mist eliminator		X							

Manpower Requirements--

Table 3-5 presents general manpower requirements for maintenance involving scaling and plugging for both the wet approach and liquid injection type venturi scrubbers. The preceding discussion has given an indication of maintenance items, maintenance times, and spare parts inventory for a venturi scrubber system. Table 3-6 completes this picture by presenting the types of personnel generally required to perform maintenance on various parts of the venturi scrubber system.[9]

Table 3-5. MANPOWER REQUIREMENTS FOR MAINTENANCE INVOLVING PLUGGING AND SCALING OF VENTURI SCRUBBER[9]

	Type of problem			
	Plugging		Scaling	
Type of venturi scrubber	Mechanical cleaners	Cylinder cleaners	Chemical cleaning	Hand cleaning
Wet approach	1 man/shift/mo	1 man/shift/mo	3 men/shift/wk	1 man/shift/wk
Liquid injection	1 man/shift/mo	1 man/shift/mo	3 men/shift/wk	1 man/shift/wk

Table 3-6. TYPE OF MAINTENANCE REQUIRED - VENTURI SCRUBBER SYSTEMS[9]

Section of the system	Type of worker				
	Maintenance man				
	Laborer	Electrical	Plumber	Wastewater treatment operator	Mechanical
Scrubber	X				
Separator	X				
Fan		X			
Pump		X	X		X
Piping, valves			X		
Water treatment equipment		X	X	X	X

3.4 OPERATION AND MAINTENANCE OF FABRIC FILTERS

3.4.1 Background Information on Fabric Filter Operation

A fabric filter baghouse consists of a large metal box divided into two chambers of plenums, one for dirty air and one for clean air. Rows of fabric bags form a partition or interface between the plenums. A polluted gas stream is ducted into the dirty-air plenum, where it is distributed evenly to the bags. The gas passes through the bags, enters the clean-air plenum, and is exhausted into the atmosphere through a stack.

Upon startup of a baghouse with new bags some stack emissions are usually visible. This is because the bag fabric, which is the filtering medium, is porous and some of the fine particulate passes through the interstices between the fibers. After a short time, however, a dust cake builds up on the surface of the bags and becomes the actual filtering medium. The bags then act as a matrix to support the dust cake.

Buildup of the dust cake is desirable until the system reaches a certain pressure drop, at which point the bags must be cleaned. Improper cleaning will cause the pressure drop to increase; if it becomes high enough, particles of dust may be forced into the bag filter, causing the bags to become "blinded." When this happens, air flow is restricted and the bags may have to be replaced or removed and cleaned to restore proper operating capacity. In addition to the costs of replacement and cleaning, high pressure-drop increases the cost of moving air through the system.

A typical reverse-air or shaker-type baghouse is shown in Figure 3-3, and a pulse type baghouse is presented in Figure 3-4. Operation of the various types of cleaning mechanisms is discussed below.

Shake: Many mechanical shaking methods are in use. Most commonly, bags are shaken from the upper fastening. Several combinations of horizontal and vertical motion can be used. The bags may all be fastened to a common framework moving horizontally or the frame may have slight additional upward or downward swing, depending on the linkage holding the framework. The framework can also be oscillated vertically.

During the shake, the filtering should be stopped. Otherwise, the dust will work through the cloth, reducing the efficiency and possibly damaging the cloth by internal abrasion. An effective cleaning method involves a series of alternate flows and shakes. This motion provides a gentle treatment of the cloth, and the cleaning is uniform and thorough.

In a typical cycle, the inlet flow to the compartment is first dampered off by a timer. If necessary, the outlet vent is also closed (Figure 3-5). In the absence of an air lock between adjacent hoppers, it may be necessary to close a damper to prevent the intrusion of dirty air from hoppers still operating. There should be zero forward pressure across the fabric during shaking, since otherwise dust will work through the fabric. The timer starts the shaker motor, and the bags are shaken. Shaking continues for about 10 to 50 cycles, each cycle taking about 0.2

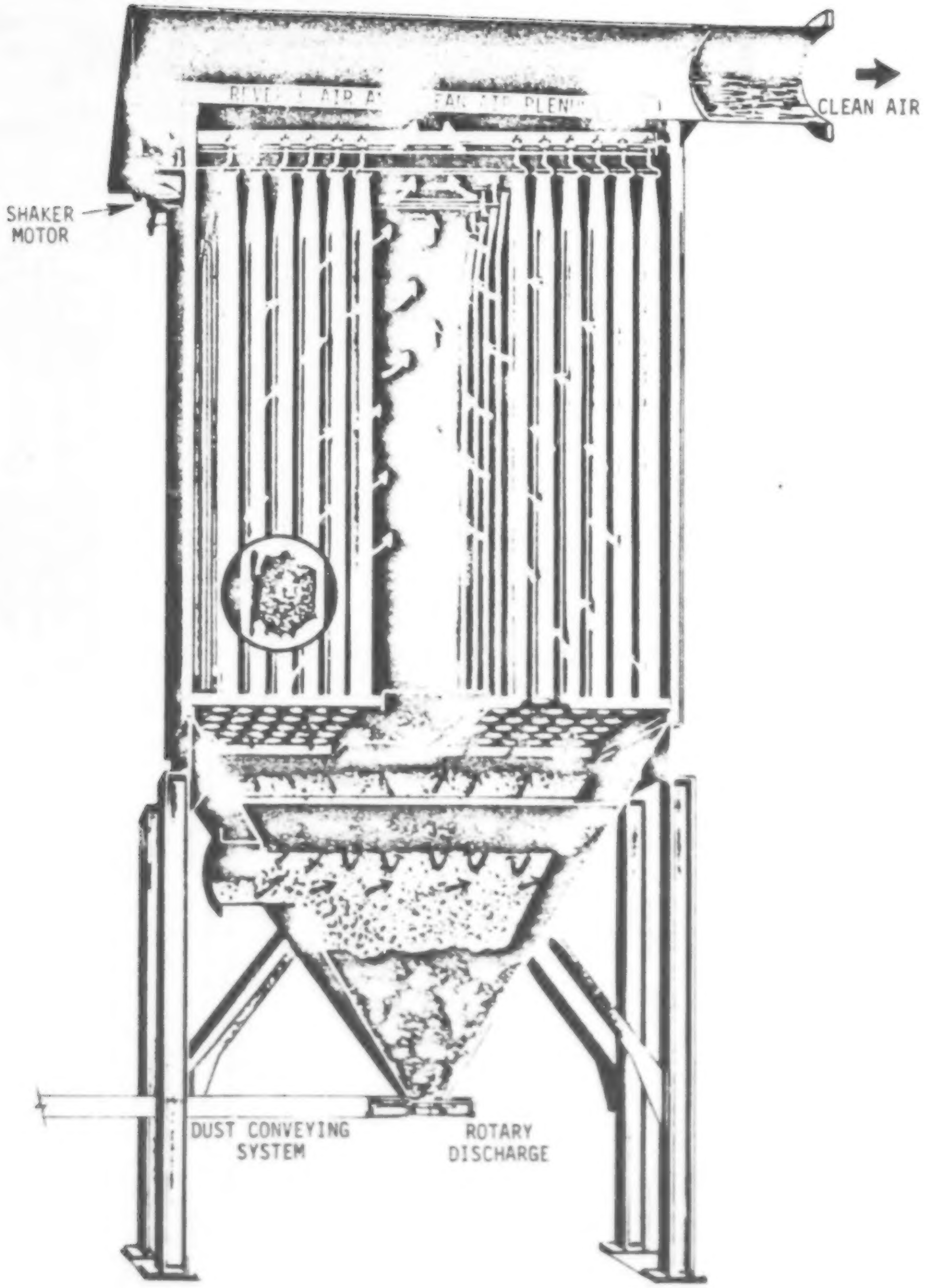

CLEAN AIR
SHAKER MOTOR
DUST CONVEYING SYSTEM
ROTARY DISCHARGE

Figure 3-3. Reverse air or shaker type.

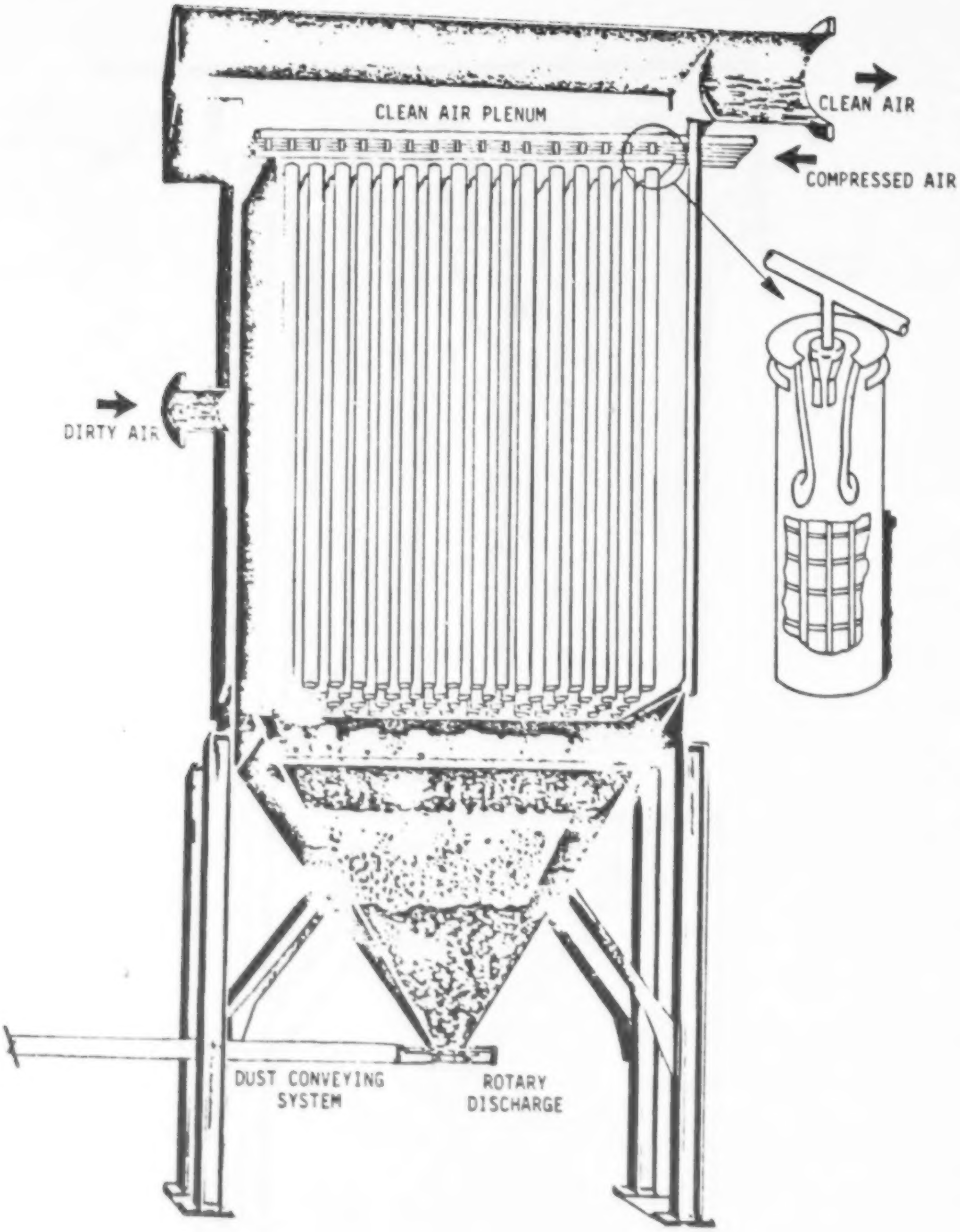

CLEAN AIR
CLEAN AIR PLENUM
COMPRESSED AIR
DIRTY AIR
DUST CONVEYING SYSTEM
ROTARY DISCHARGE

Figure 3-4. Pulse jet type.

to 1 second. Then the timer may start a slight flow of clean reverse air using an auxiliary blower for 10 to 20 seconds. The shaking may be repeated, this time during the reverse flow. Finally, the cleaning is stopped and after a pause to allow the dust to settle, the inlet and outlet dampers are opened and the compartment resumes filtering. The entire cleaning cycle may take from 30 seconds to a few minutes. Some installations do not return the compartment on line until the next one is ready to be cleaned, thereby achieving a fairly steady overall flow through the baghouse system at the expense of some over-capacity.

Reverse Flow: If the dust can be released fairly easily from the fabric, a low-pressure reversal of the flow may be enough to loosen the cake without mechanical agitation. To minimize flexural attrition of the fabric, it is supported by a metal grid, mesh, or rings and is usally kept under some tension. The support is usually on the clean side of the tube or bag, although dirty-side support can help to keep the sides of the bag or the panels far enough apart to allow the cake to fall to the hopper.

Flow reversal is achieved in several ways. In addition to the standard dampers on each compartment, each one can have its own reversing fan. A few models have a traveling apparatus that goes from bag to bag or from panel to panel, blocking off the primary flow and introducing some air in the reverse direction with a secondary blower. A simpler method is to take advantage of suction on the dirty side or of relative pressure on the clean side without using another blower, as shown in Figure 3-6.

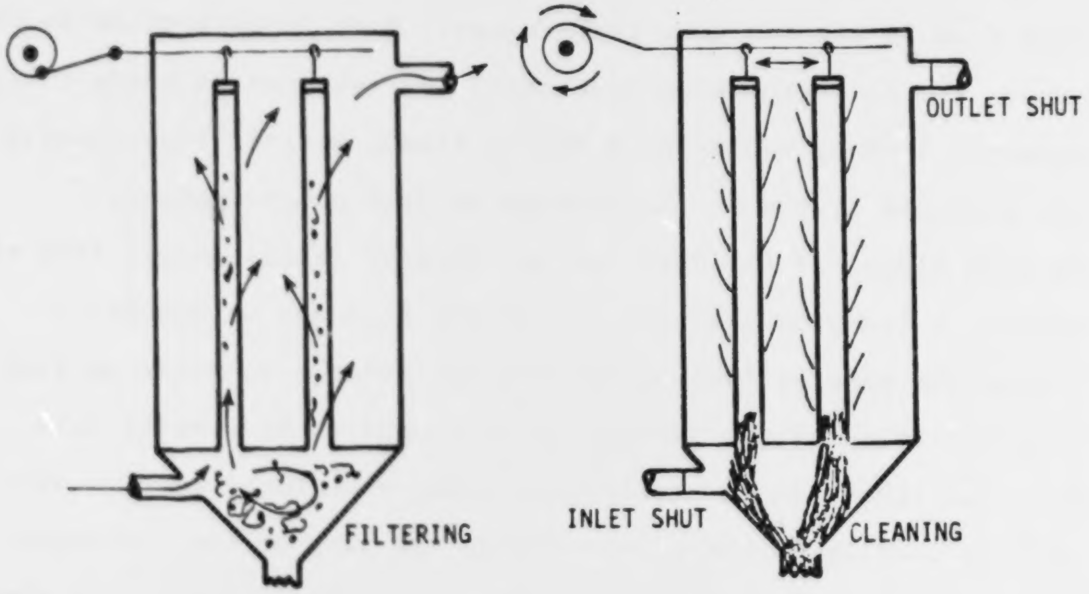

OUTLET SHUT
FILTERING
INLET SHUT
CLEANING

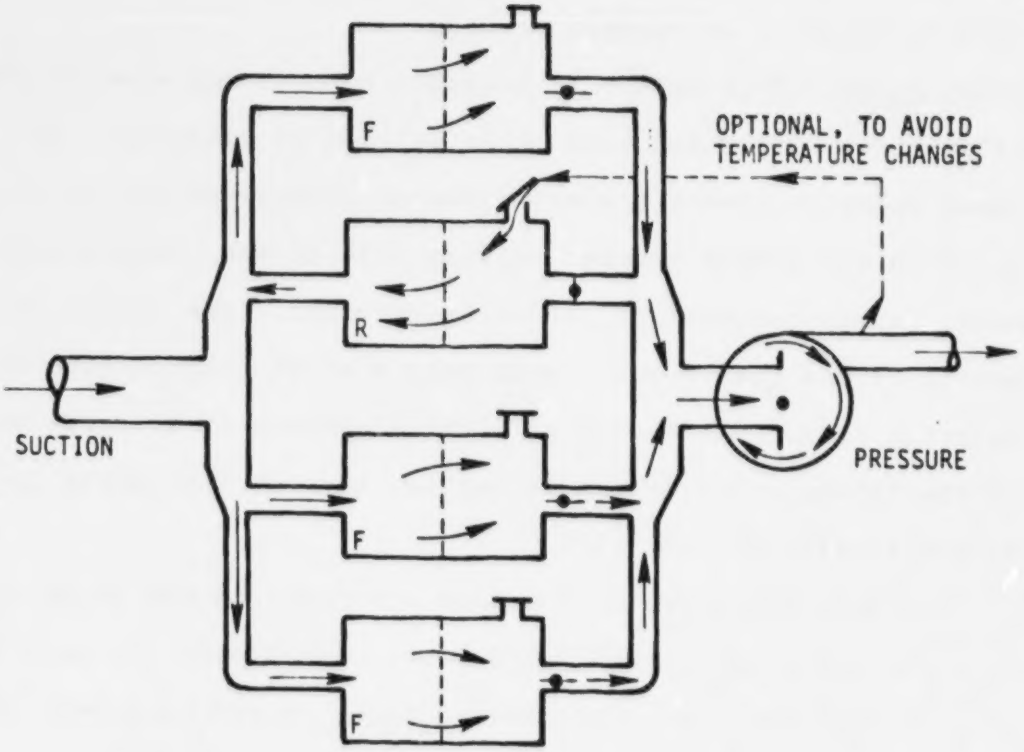
Figure 3-5. Diagram showing normal operation and shake cleaning of a fabric filter.[10]

Any flow volume reversed through the filter must be refiltered. Therefore in addition to taking cloth out of the system for cleaning, this cleaning method increases the total air flow in the remainder of the system. The net increase in air/cloth ratio is normally 10 percent or less.

Plenum Pulse: This method is intended to overcome some of the difficulties associated with other methods of cleaning. In plenum pulse equipment a sharp pulse of compressed air is released in the plenum chamber, giving rise to some combination of shock, fabric deformation, and flow reversal. The result is the removal of the dust deposit with only a brief interruption of the filtering flow. The fabric receives a minimum of flexural wear, and the filter installation is smaller because the fabric is in use practically all the time.

The main distinction of pulsed equipment is the brief cleaning time, typically around 0.1 second. Because of the very low ratio of cleaning time to filtering time, pulsed equipment is especially useful with heavy dust loadings.

Pulsed Jet: This cleaning method is similar to plenum pulse cleaning. The difference is that in pulse jet cleaning each bag is individually pulsed, whereas in plenum pulse cleaning the whole compartment of bags is pulsed by introduction of pulsing air in the plenum chamber.


OPTIONAL, TO AVOID TEMPERATURE CHANGES
F
R
SUCTION
PRESSURE
F
F

F: COMPARTMENTS FILTERING

R: COMPARTMENT BEING CLEANED BY DAMPERED CONTROL FROM SUCTION SIDE OF SYSTEM

Figure 3-6. Schematic for reverse flow cleaning during continuous filter operation.[10]

Vibration or Rapping: This method of cleaning is particularly successful with deposits that adhere relatively loosely to the bags. The vibration or rapping produces stresses at the fabric-cake interface, causing release of the dust cake from the fabric.

Sonic Assist: Engineers have attempted to produce agitation frequencies still higher than those used in vibration or rapping with ultrasonic and sonic cleaning methods. Although cleaning at these frequencies slightly improves the preagglomeration of a few fine dusts, the systems generally have not been very effective in fabric cleaning.

3.4.2 Fabric Filter Startup and Shutdown Procedures

Preoperation Checks--

The following checks are recommended prior to startup:

- Test control air lines (hydrostatically).
- Check air dryers that supply control air to the bag filters.
- Check dust removal system.
- Inspect collapse air fans for alignment and rotation.
- Check seals at gas inlet, collapse air, and gas outlet damper.
- Check baghouse compartments, remove debris.
- Check filter bags for proper installation and tension.
- Check and sweep thimble floors clean. Dust buildup on floor during operation is positive indication of a broken bag.
- Calibrate pressure drop recorders and transmitters.
- Check pressure taps for leakage.

Startup--

Although operation of a fabric filter system is virtually completely automatic, startup and shutdown are extremely critical.

When the new equipment is started for the first time, the fan should be checked for correct direction of rotation and speed. The ducting, collector housing, etc., should be checked for leaks. Gas flows and pressures should be checked against the design specifications. Instruments should then be checked for correct reading and calibration adjustments made as necessary. Control mechanisms, and especially all fail-safe devices, should be checked for operability.

At the first startup of the system, and also whenever new bags have been installed by the maintenance crew, the bags should be checked after a few hours of operation for tension, leaks, and expected pressure differential. Initial temperature changes or the cleaning cycle can pull loose or burst a bag. It is wise to record at least the basic instrument readings during this initial startup with new bags for ready reference and comparison during later startups.

During any startup, transients in the dust generating process and surges to the filter house are probable and ought to be anticipated. Unexpected temperature, pressure, or moisture may badly damage a new installation. In particular, running almost any indoor air or combustion gases into a cold filter can cause condensation on the walls and cloth, leading to blinding and corrosion. Condensation in the filterhouse may void the manufacturer's guarantee. It can be prevented by preheating the filter or the gas.

A typical sequenced startup procedure for a large continuous, automatic, multicompartment fabric filter using either reverse air, shake, or combination cleaning is summarized as follows:

1. Check to see that all system monitoring instruments are reading zero; especially fan motor ammeters and compartment pressure manometers.
2. Close all system dampers except tempering air damper (if used). This includes main compartment isolation dampers, reverse air dampers (if used), and fan modulation dampers.
3. Start material handling system including any motorized airlock devices and screw conveyors. Hoppers should be empty on startup.
4. Sequentially start main fans, allowing each to come to speed before starting next fan.
5. Start separate reverse air fan if used and allow to come to speed.
6. Engage fan modulating damper circuit(s).
7. Engage tempering air damper circuit (if used).
8. Slowly open main-compartment isolation dampers. If dampers are opened too quickly, bags will pop open, ultimately resulting in failure.
9. Engage compartment cleaning recircuit.
10. Check normalcy of readings on system monitoring instruments, especially fan motor ammeters and compartment pressure manometers.

Shutdown--

1. After process has been stopped and is no longer evolving emissions, allow baghouse to track through one complete cleaning cycle; this will purge system of process gas and collected dust.
2. Stop main fans.
3. Stop separate reverse air fan, if used.
4. Allow material removal system to operate for 1 hour or until system is purged of collected material.

3.4.3 Inspection and Maintenance During Normal Operation

This section presents general maintenance procedures that can be applied to fabric filters. on kraft pulp mill power boilers and crushed stone operations. Table 3-7 presents a checklist of items that require regular inspection.

Plant personnel must learn to recognize the symptoms that indicate potential problems in the fabric filter, determine the cause of the problem and remedy it, either by in-plant action or by contact with the manufacturer or other outside resource.

High pressure drop across the system is a symptom for which there could be many causes, e.g., difficulties with the bag cleaning mechanism, low compressed-air pressure, weak shaking action, loose bag-tension, or excessive reentrainment of dust. Many other factors can cause excessive pressure drop, and several options are usually available for corrective action appropriate to each cause. Thus the ability to locate and correct malfunctioning baghouse components is important and requires a thorough understanding of the system. A detailed list of troubleshooting and corrective measures is given in Appendix B-4.

Table 3-7. CHECKLIST FOR ROUTINE INSPECTION OF BAGHOUSE[9]

Component[a]	Check for:
Shaker mechanism(s)	Proper operation without binding; loose or worn bearings, mountings, drive components; proper lubrication
Bags	Worn, abraded, damaged bags; condensation on bags; improper bag tension (S) (RF); loose, damaged, or improper bag connections
Magnehelic gauge or manometer	Steadiness of pressure drop (should be read daily)
Dust removal system	Worn bearings, loose mountings, deformed parts, worn or loose drive mechanism, proper lubrication
Baghouse structure (housing, hopper)	Loose bolts, cracks in welds; cracked, chipped, or worn paint; corrosion
Ductwork	Corrosion, holes, external damage, loose bolts, cracked welds, dust buildup
Solenoids, pulsing valves (RP)	Proper operation (audible compressed air blast)
Compressed air system (RP, PP)	See above; proper lubrication of compressor; leaks in headers, piping
Fans	Proper mounting, proper lubrication of compressor; leaks in headers, piping
Damper valves (S, PP, RF)	Proper operation and synchronization; leaking cylinders, bad air connections, proper lubrication, damaged seals
Doors	Worn, loose, damaged, or missing seals; proper tight closing
Baffle plate	Abrasion, excessive wear

[a] RP-reverse pulse; PP-plenum pulse; S-shaker; RF-reverse flow.

Table 3-8 presents the frequency of failure of basic fabric filter parts, frequency of inspection and inspection time, and time required for repairs.

Following is a discussion of major fabric filter components requiring routine maintenance:

Inlet Dusting--

Common problems such as abrasion, corrosion, sticking or plugging of dust, and settling must be dealt with on a routine basis. Abrasion can be reduced by using special materials at bends in ducting. Corrosion can be minimized by supplying insulation, especially in the long duct runs, which are most susceptible to moisture condensation. Regular inspection will help control plugging and dust settling in ducts.

Blast Gate and Flow Control--

Problems with flow control equipment are reported frequently.[10] The blast gate valve is especially vulnerable and should be checked periodically and adjusted. Filter compartment inlet dampers are a high-maintenance item, and spare parts should be stocked.[10] A bad damper seal can shorten the life of bags in a shake-type system, and caking bags, if not replaced, can foul valves on the clean side of the baghouse and cause them to malfunction. The most popular dampers for compartment isolation are air cylinder-operated poppets acting vertically (see Figure 3-7). Maintenance on these dampers consists of periodic inspection and replacement of packing and solenoids. Damper failures can sometimes be detected by observation of a differential

Table 3-8. BAGHOUSE COLLECTOR MAINTENANCE[9]

Item	Frequency of breakdown	Frequency of inspection	Time required to perform inspection	Time to repair	Type of person to repair	Comments
INSIDE BAG COLLECTION						
Bags						
5 in. Ø 14 ft	Monthly	Monthly	1.5-3 man-h/100 bags[a]	10-30 min/bag[b]	Laborer[c]	Complete replacement
8 in. Ø 22 ft	Monthly	Monthly	2-4 man-h/100 bags[a]	15-45 min/bag[b]	Laborer[c]	2 years same
12 in. Ø 30 ft	Monthly	Monthly	2.5-5 man-h/100 bags[a]	20-60 min/bag[b]	Laborer[c]	Same
Door seals	2-4 yr	Monthly	5 min/door	1 h/door	Laborer	
Cleaning mechanism						
Shaker	6 mo	Monthly	5-min/row	30 min/row	Maint. man	
Reverse air	2 yr	Monthly	15 min	2 h	Maint. man	
Dust removal system						
Screw conveyors	1-2 yr	6 mo	1 h	2-4 h	Maint. man	
Air locks	1-2 yr	6 mo	30 min	1-2 h	Maint. man	
Pneumatic	2-3 yr	6 mo	1 h	8 h	Maint. man	
Baffle plate	4 yr	1 yr	30 min	8 h	Maint. man	
Damper valves	2-3 yr	Monthly	15 min/valve	1-24 h	Maint. man	
OUTSIDE BAG COLLECTOR						
All bags	Monthly	Monthly	0.6 man-h/100 bags	6-10 min/bag	Laborer	Assume top bag removal
Cleaning mechanism						
Pulse jet	2 yr	Monthly	2 min/row	30 min	Maint. man	
Pulsing plenum	2 yr	Monthly	2 min/row	1 h	Maint. man	
Door seals	2-4 yr	Monthly	5 min/door	1 h/door	Laborer	
Dust removal system						
Screw conveyors	1-2 yr	6 mo	1 h	2-4 h	Maint. man	
Air locks	1-2 yr	6 mo	30 min	1-2 h	Maint. man	
Pneumatic	2-3 yr	6 mo	1 h	8 h	Maint. man	
Baffle plates	4 yr	1 yr	30 min	8 h	Maint. man	
Damper valves	2-3 yr	Monthly	15 min/valve	1-24 h	Maint. man	

[a] 1.5 man-h/bag for 24 in. reach, 3.0 man-h/100 bags for 36 in. reach (time may be cut by 70% if rejection of fluorescent particles and black light are used).

[b] Low value is total changeout/bag and high value is individual bag change.

[c] Three-man crew minimum.

pressure chart. As the dampers open and close, the differential pressure swings. If a damper fails, the absence of this pressure swing leaves a "gap" on the differential pressure chart. If a high differential pressure is signaled, the dampers are routinely checked for proper operation. If not, the operator must observe damper operation through the complete cycle directly at the baghouse.

Fans--

Fans and blowers are reported to present many problems, particularly those located on the dirty side of the baghouse where material can accumulate on the vanes and upset the balance.[10] Corrosion and abrasion of fans can also cause problems. The use of pressure-style baghouses has been dramatically reduced, however, because of the necessity for on-line maintenance and the danger associated with working on a pressure type inside bag collector.

Condensation and corrosion in the fan may be alleviated with duct and fan insulation.[10] Most fan housings can be drained, and the drains should be checked regularly.

Air flow and fan speed should be measured periodically and belt condition and tension determined; the fan should also be checked for direction of rotation. These checks can be combined with routine lubrication procedures.

Entrance Baffles--

Any baffles added to improve the distribution of gas to each compartment and bag should be adjustable. Baffles may cause

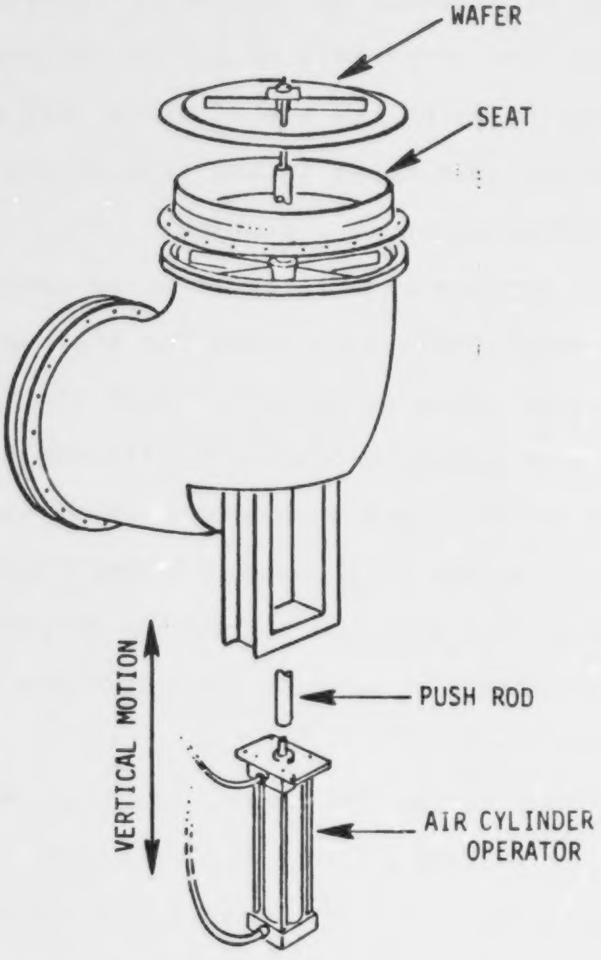

WAFER
SEAT
PUSH ROD
VERTICAL MOTION
AIR CYLINDER OPERATOR

Figure 3-7. Poppet valve.

problems by accumulating dust or abrading too rapidly.

Hoppers--

Hoppers are a common problem in any fabric filter system. Dust flow can be facilitated by the use of vibrators and/or heaters (if they work properly); by lining the hoppers with antifriction materials; by the use of air-pulsed rubber-lined hoppers; by placing poke holes in the side of the hoppers; or by insulation if condensation is a problem.

Trough-type hoppers with integral screw conveyors are the most common material handling systems for kraft pulp mill power boilers and crushed stone operations. Dust storage in baghouse hoppers is a common industry practice, although this frequently results in dust bridging and subsequent use of sledgehammers to break the dust bridge in hoppers. Hopper vibrators can be used but are expensive and have a tendency to pack the dust and aggravate the problem if vibration amplitude and frequency are not correctly selected.

Regular inspection of the hopper (once per shift) is mandatory to alleviate problems with the suction-removal system or those caused by bridging of dust before they become serious.

The screw conveyor flighting inside the hoppers is supported every 10 to 15 feet by nonlubricated sleeve-type hanger bearings (see Figure 3-8). Wear on these sleeves and on outboard packed bearings is the major screw conveyor maintenance problem. The most common sleeve material is cast iron, although Babbitt, wood, and various other material have been used.

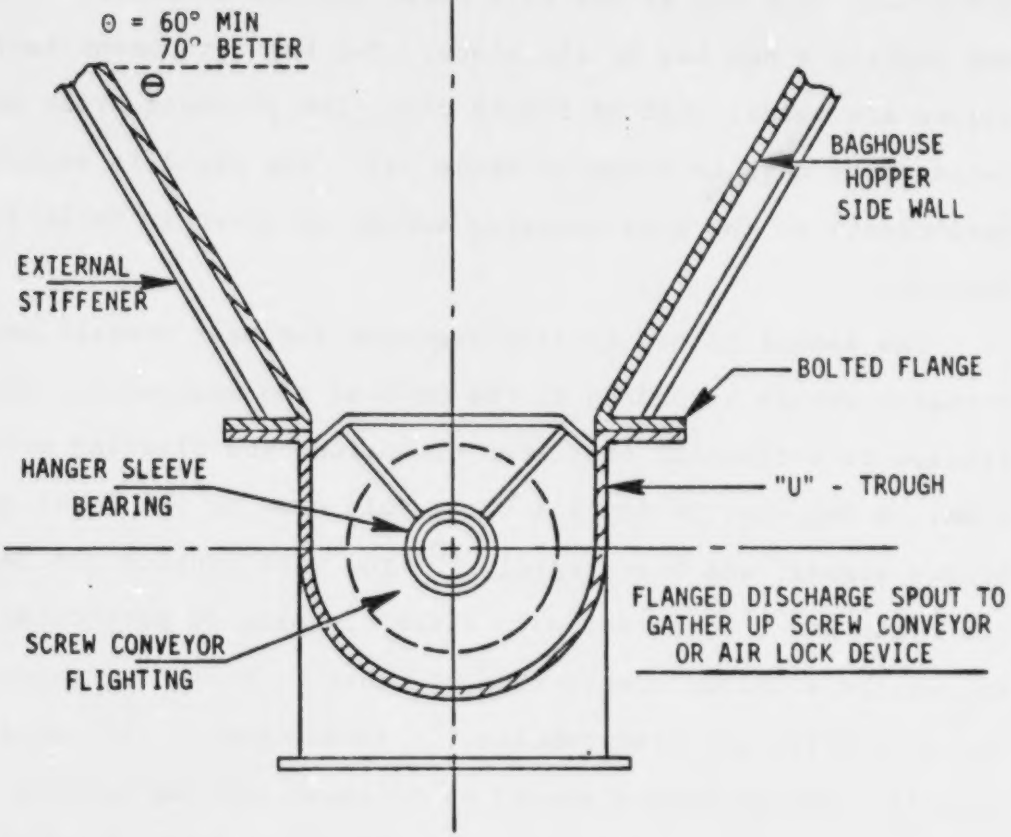

Θ = 60° MIN
70° BETTER
Θ
BAGHOUSE
HOPPER
SIDE WALL
EXTERNAL
STIFFENER
BOLTED FLANGE
HANGER SLEEVE
BEARING
"U" - TROUGH
FLANGED DISCHARGE SPOUT TO
GATHER UP SCREW CONVEYOR
OR AIR LOCK DEVICE
SCREW CONVEYOR
FLIGHTING

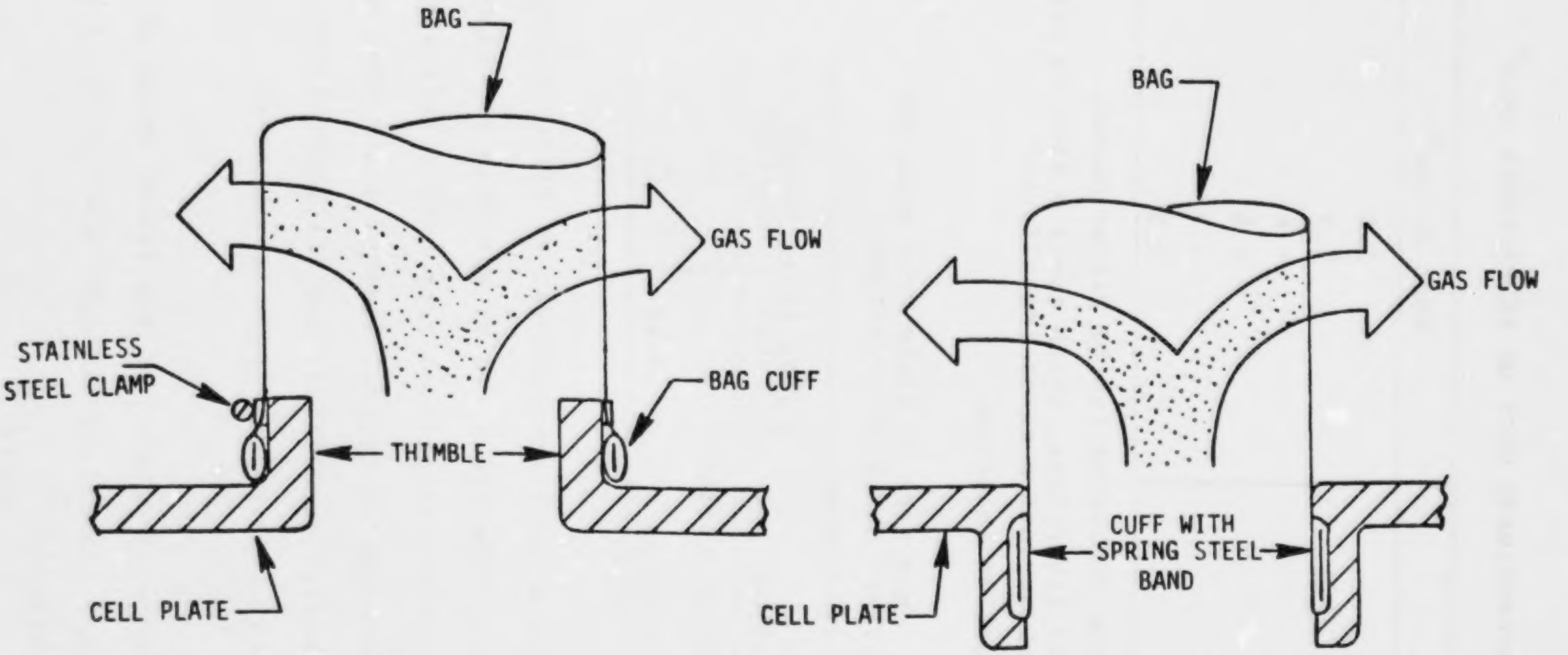
Figure 3-8. Typical trough hopper and screw conveyor arrangement.

Bag Replacement--

The most expensive maintenance operation for fabric filter systems is the complete change of a set of bags. This is accomplished by a crew of two to six men, who enter the baghouse and disconnect each bag at the cell plate and top suspension level and install a new bag in its place. Two bag attachment techniques are illustrated in Figure 3-9. The purchase price of replacement bags is given in Table 3-9. The bag life reported by respondents to the questionnaire survey is given in Table 3-10.

Tension-

The amount of bag tension required for best overall performance varies according to the make of the equipment. Correct tension is a function of filter dimensions and cleaning mechanism. A bag that is too slack can fold over at the lower cuff, bridge across, and wear rapidly.[10] Too much tension can damage the cloth and the fastenings. Shake cleaning in particular seems to require a unique combination of tension, shake frequency, and bag properties for best results.[10] In any event, the manufacturer's recommendations should be followed and the tension checked periodically, especially a few hours after installing a new bag.


BAG
GAS FLOW
STAINLESS STEEL CLAMP
BAG CUFF
THIMBLE
CELL PLATE
BAG
GAS FLOW
CUFF WITH SPRING STEEL BAND
CELL PLATE

SNAP BAND CONNECTION

THIMBLE CONNECTION

Figure 3-9. Bag-cell plate attachments.

Table 3-9. APPROXIMATE COST OF REPLACEMENT BAGS[a]

Material	Cost factor[b]
Fiberglass	1.0
Nomex	2.5
Kermel	≈ 6
Gortex	≈ 5
Teflon[c]	≈ 7
Acrylic	1.2

[a] Based on data from the McIlvaine Fabric Filter Manual.

[b] As compared to coated fiberglass, which costs 0.65-1.00 per ft^2, depending on manufacturer and size of installation.

[c] Reflects recent reduction in price.

Table 3-10. BAG LIFE IN KRAFT PULP MILL AND CRUSHED STONE APPLICATIONS

Application	Bag life, months	
	Range	Average
Kraft pulp mill power boilers		15
Crushed stone industries	9-48	18

Spare Stock--

It is advisable to stock a complete set of filter elements in case of an emergency. The spare filter elements should be clearly labeled and kept well-separated from used filter elements.[10] Table 3-11 presents a typical list of items that should be stocked, the approximate quantities, and the approximate delivery time and costs of parts that must be purchased.

Inspection Frequency--

External maintenance inspection of the filter house is usually performed daily; the filter elements are typically inspected weekly or monthly.[10]

Table 3-11. LIST OF REPLACEMENT PARTS FOR A BAGHOUSE FILTER[9]

Type of part	Quantities to stock, % of total in baghouse	Delivery time if not stocked, weeks	Estimated cost, $	Comments
Bags	15	4-8	See Table 3-9	
Door seals	20	2-4	10/seal	Typical 18 × 48 in. door
Mechanism				
Shaker	20	2-4	10/item	Bearings, knife blades, belts
Reverse air	100	6-10	25/item	Belts
Pulse jet	20	2-4	3/item	Valve rebuild kit
Pulsing plenum	20	2-4	5/item	Solenoid valves, seals, cylinders
Screw conveyor	20	8-10	10/item	Bearings
Air locks	100	8-10	10/item	Seals
Pneumatic		8-10		Variable
Baffle plates		4-6	100/plate	
Damper valves	20	4-6	10/item	Solenoid valves, seals, cylinders

Shake Cleaning--

Shaker mechanisms are generally simply supported from each end by knife-edge bearings set in grooved blocks. A fractional horsepower motor is used with a yoke linkage to oscillate the shaker bars (see Figure 3-10). Shaker mechanism maintenance is centered on the drive arrangement. Periodic lubrication of bearings and checking of alignment are required. The shaking machinery should also be checked periodically for wear. If the bags are not being cleaned properly, sometimes a minor adjustment of the shake amplitude or frequency can markedly improve cleaning. If a safe amount of shaking still does not properly clean the clots, it may be necessary to reduce the filtration velocity for a few hours.[10]

Reverse-Flow Cleaning--

With this type of cleaning, the only maintenance requirement is to check the rate of flow (back pressure) and the timing periodically to keep the residual drag at an economical level.

Shake and Reverse-Flow Cleaning--

As in shake cleaning, wherever the bag is flexed the rate of wear is apt to be high. Maintenance procedures outlined for the shake and reverse-flow methods also apply here.

Pulse Jet Cleaning-

Since the pulse type apparatus contains almost no moving parts, hardware maintenance is reduced in comparison with requirements for other cleaning methods. Excessive use of air cleaning pressure can damage bags by overstretching them. Cor-

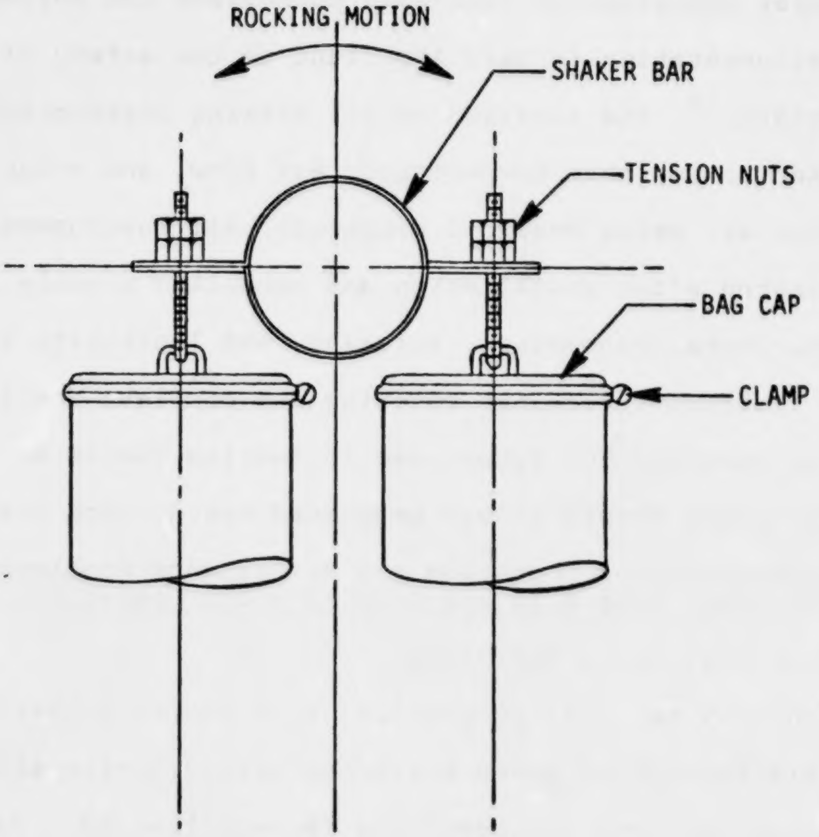

ROCKING MOTION
SHAKER BAR
TENSION NUTS
BAG CAP
CLAMP

Figure 3-10. Typical shaker arrangement.

rective measures include reducing the frequency of cleaning, using another type of bag fabric, or reducing the abrasiveness of the dust.

Instrumentation--

Proper operation of fail-safe mechanisms and automatic control instrumentation is very important to the safety of the filter cloth.[10] The location of all sensing instruments should be checked to see that temperature, air flow, and other operating conditions are being measured properly. All instruments should be calibrated after installation and rechecked monthly for sensor location, leaks (manometer), sticking, and legibility of readout.[10] Instrument readings covering one complete operating cycle should be recorded for future use in routine checks and troubleshooting. This record should be posted beside each instrument.

3.4.4 Fabric-Filter Operation and Maintenance Problems Specific to Kraft Pulp Mill and Crushed Stone Operations

Kraft Pulp Mill Power Boilers--

With only two U.S. pulp mills using fabric filters to control their bark-fired power boiler emissions, information on maintenance problems and practices is very limited. Just one of the two companies was able to produce some maintenance data.

The primary problem with operation and maintenance of the two collectors at Simpson Timber centers on the collection hoppers. They have experienced plugging problems due to the very light nature of the collected dust. Even though the screw conveyor can adequately handle the volume of material emptying from the hoppers, the material tends to bridge. Much of the dust consists of submicron NaCl particles. To remedy the situation, Simpson Timber is trying out a hopper vibrator system that actuates at the end of each cleaning cycle. This system appears to be relieving the plugging. The Simpson personnel also hope to develop a good method of sensing that will indicate when the hoppers begin to plug up. To date they have not devised a reliable mechanism.

Simpson installed a bypass chute on the baghouse hopper for use during cleanout operations. The screw conveyors could not handle the large volume of material released when a plugged hopper was dislodged, so the chute was provided to relieve the extra load.

Except for some operational problems that arose during the initial few months of operation, the two baghouses have run satisfactorily for over 2 years. Routine maintenance is, of course, performed. Every 3 to 6 months, when the system is off line, the fan housings and impellers are cleaned by blowing them out with compressed air. Vibration detectors have been installed on the fan to warn of impending imbalances. This system allows maintenance personnel to clean the fans before a scheduled inspection if needed.

Bag life is reported to average around 15 months. The usual cause of bag failure is abrasion against the support cage.

Crushed Stone Processes--

Since the baghouse systems serving crushed-stone processing plants are small and many have been installed within the past 2 or 3 years, maintenance data are very sketchy. Plant personnel rarely keep adequate records. The major problems seem to be related to the cleaning mechanism and the dust-removal system. Minor problems occur with other segments of baghouses, but generally operating experience with fabric filtration in the industry has been good. Downtime for maintenance usually is not a serious problem because many of the processing operations do not run continuously. Baghouse maintenance can be done during nonoperating periods unless extensive repairs are needed.

Even though pulse-jet cleaning mechanisms have few moving parts when compared with shaker-type systems, they may cause their share of operating difficulties. At one plant, visited during this study, major maintenance items were the blowdown valves and diaphragms associated with the pulse-jet system. These components failed at the rate of almost one a week. Problems were also encountered with the air compressor bearings and drive belts. The bearings had to be replaced after only about 4 months of use, and the drive belts also wore quickly. In addition, the pulse-jet system was regulated by solid-state circuit cards, which have sometimes failed and needed replacement.

Another plant, reported similar difficulties with their pulse-jet system. Diaphragms have failed, and the cycling mechanism has malfunctioned on several occasions.

Problems with dust removal/conveying systems have plagued several of the baghouse installations surveyed. Failure of rotary air locks to remove collected dust from hoppers fast enough is a common complaint. This sometimes results in the material packing in the hopper as it backs up, bridging the opening just above the airlock. It then becomes necessary to rap the outside of the hopper to dislodge the dust. Screw conveyors also are reported as a fairly major maintenance item. At least two installations reported broken shafts resulting from overloading the screw. Maintenance personnel at one plant experienced repeated problems with broken shaft pins. The shaft pin connects the motor shaft to the screw shaft and will shear when the screw overloads while the motor still tries to turn at a constant speed. This problem was most pronounced upon startup on the morning after collected dust had remained in the hopper and screw overnight. The baghouse is now run for a short period each night before shutdown to clear the screw of any remaining material.

Other baghouse installations surveyed reported no particular maintenance problems with their dust conveying systems other than routine maintenance, e.g., repacking bearings, cleaning out solidified material. One of the maintenance personnel recommended that baghouse manufacturers provide access panels beneath the screw conveyor for easier cleanout. With present designs, someone must enter the baghouse hopper with a light and dig out the screw from above.

This employee also suggested that baghouses be equipped with some sort of warning device, either a flashing light or rotating flag, to indicate when the screw shaft breaks from the motor shaft. From a distance, it is difficult to tell that the screw has stopped turning because the drive motor continues to operate.

The ID fans used with the pulse-jet type baghouse are a relatively low maintenance item. One plant reported that they check the fan impeller housing every 3 to 6 months, depending on the ambient weather conditions. Because dust buildup on the impeller blades causes an imbalance and increases bearing wear, it is advantageous to keep the fans reasonably clean. Erosion of the blades is not a problem because the rock dust is not highly abrasive.

Bag life in fabric filters at crushed stone plants may range from 9 months to 4 years or more. The average bag life in the industry appears to be about 1-1/2 to 2 years. The usual cause of bag failure is abrasion against the cage supports (for pulse-type collectors). Excessive moisture in the baghouse inlet air during wet ambient conditions may pose a problem of bag caking. In most cases, however, dry dust emissions are minimized during wet weather and the collectors can usually be turned off.

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SECTION 4

'FRACTIONAL EFFICIENCY RELATIONSHIPS

4.1 INTRODUCTION

This section evaluates the total mass and fractional efficiency capabilities of precipitators, scrubbers, and fabric filters on kraft pulp mill and crushed stone industry processes. Unfortunately, the availability of fractional efficiency test data on these processes is very limited, and numerous contacts with users and manufacturers have yielded none; however, fractional efficiency test data for electrostatic precipitators (ESP's) on kraft pulp mill recovery boilers and a mobile fabric filter test on a lime kiln were obtained from the literature.

Results from computer models for ESP's and venturi scrubbers are presented, which predict penetration as a function of particle size. An appropriate predictive model is not available for use with fabric filters.

4.1.1 Limitation of Current Data

Only in the past 4 or 5 years has particle size distribution been measured and recorded with any regularity by control equipment manufacturers, independent testing companies, and consultants; and because of operator error and the inherent technical limitations of some particle-sizing instruments, reliable data are still not readily available. Meaningful evaluation of fine particulate emissions will require development of a reliable and consistent fine-particle measuring technique that can be applied widely. A broadly applicable technique for compliance monitoring of fine-particle sources would have the added advantage of enabling the collection of valuable data concerning the subject processes in this report under different operating conditions.

4.1.2 Summary of Inlet Particle Size Distribution Data Used for Precipitator and Scrubber Models

Table 4-1 summarizes the inlet particle size distribution data used in the precipitator and scrubber model predictions. These particle size distributions are based on data from various literature sources. (See Table 4-1.).

Table 4-1. SUMMARY OF INLET PARTICLE SIZE DISTRIBUTION DATA USED IN ESP AND SCRUBBER PREDICTION MODELS

Process	$\bar{x}$, μm	σ_g, μm	Reference
Kraft Pulp Mill			
Conventional recovery boilers	1.4-1.9	3.0-2.04	1,2
Low-odor recovery boilers	1.5	2.5	3
Bark/fossil fuel-fired boilers	5-15	2.5-4.0	4
Sludge lime kilns	20	4.5	5
Crushed Stone Industry			
Jaw crushers	200	8.7	6
Conveyors	10	4	6

4.2 PROCEDURE FOR DETERMINING FRACTIONAL EFFICIENCY PERFORMANCE

4.2.1 Electrostatic Precipitator Computer Model

Two computer models used to predict precipitator performance were described earlier (Section 2.3.2). In the first model reentrainment losses are assumed to be negligible. Because reentrainment does occur with precipitators installed on bark and combination-fired boilers, another theoretical model is presented in Section 2.3.2 to account for it. This section presents selected results of applying the model to predict the fractional efficiency of an electrostatic precipitator.

Model Application to Conventional and Low-odor Recovery Furnaces--

The first theoretical model described in Section 2.3.2 (specifically equation 17) can be used to compute the outlet particle size distribution and fractional efficiencies for given values of inlet particle size distribution and required overall mass collection efficiency. Part of the program logic involves an iterative procedure in which the parameter, K, is adjusted until the computed efficiency is close to the desired value within specific limits. Once an appropriate value of K has been determined, the fractional penetrations can be estimated by use of equation 15.

Figure 4-1 shows particle penetration as a function of particle diameter for precipitators applied to conventional and low-odor recovery furnaces. The minimum collection efficiency occurs in a particle size range of 0.2 to 0.6 μm. The reason is that the electrical mobility of particles is at a minimum in this

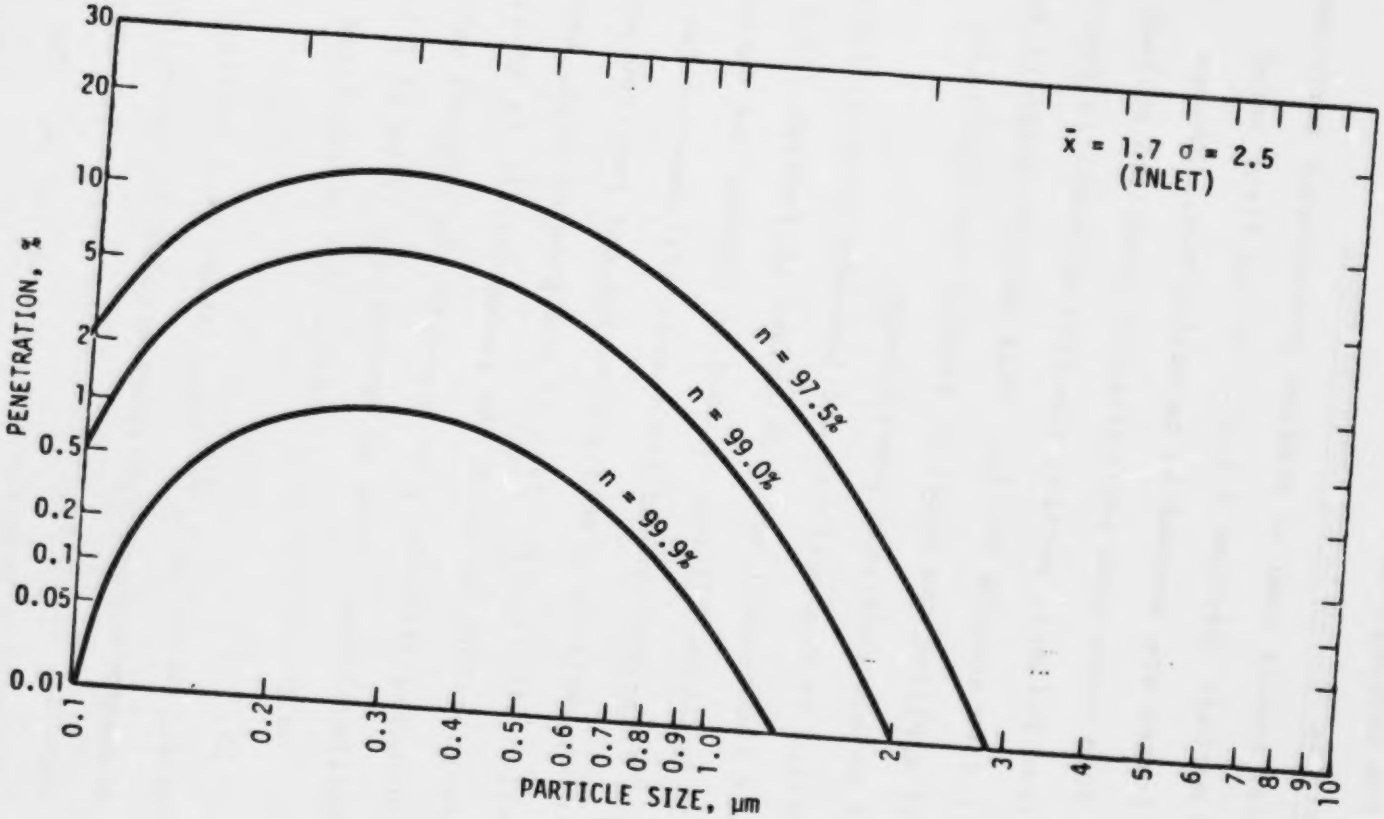

Figure 4-1. Predicted precipitator penetration for conventional and low-odor recovery furnaces.

size range. Note that the field charging equation is important for particles greater than 0.5 μm. The equation predicts particle mobilities that increase with increasing particle size. The diffusion charging theory predominates with respect to collection of particles smaller than 0.5 μm. This theory predicts that the particle mobility decreases with increasing particle size, and minimum mobility occurs in the size range of 0.4 to 0.7 μm. Thus the range of 0.2 to 0.6 μm presents the most difficult size range for operation of electrostatic precipitators.

Figures 4-2 and 4-3 are similar plots of penetration as a function of particle size for selected overall mass collection efficiency levels based on two inlet distributions having coarser particles. Although the range for minimum collection is still 0.2 to 0.6 μm, the absolute fractional efficiencies at the same overall mass collection efficiency depend very strongly on the inlet size distribution. For example, at 0.3 μm and at an overall mass collection efficiency of 99.9 percent, Figure 4-1 indicates a fractional efficiency of 98.9 percent, whereas Figures 4-2 and 4-3 show fractional efficiencies of 97.8 and 97.0 percent, respectively.

One set of fractional efficiency test data for an ESP on a kraft pulp mill recovery boiler was obtained from a report by Gooch, et. al. of Southern Research Institute (SRI).[8] These results show an average overall mass collection efficiency of 99.96 percent with a minimum average collection efficiency of 99.92 in the size range of 0.15 to 1 μm. The mass median diameter

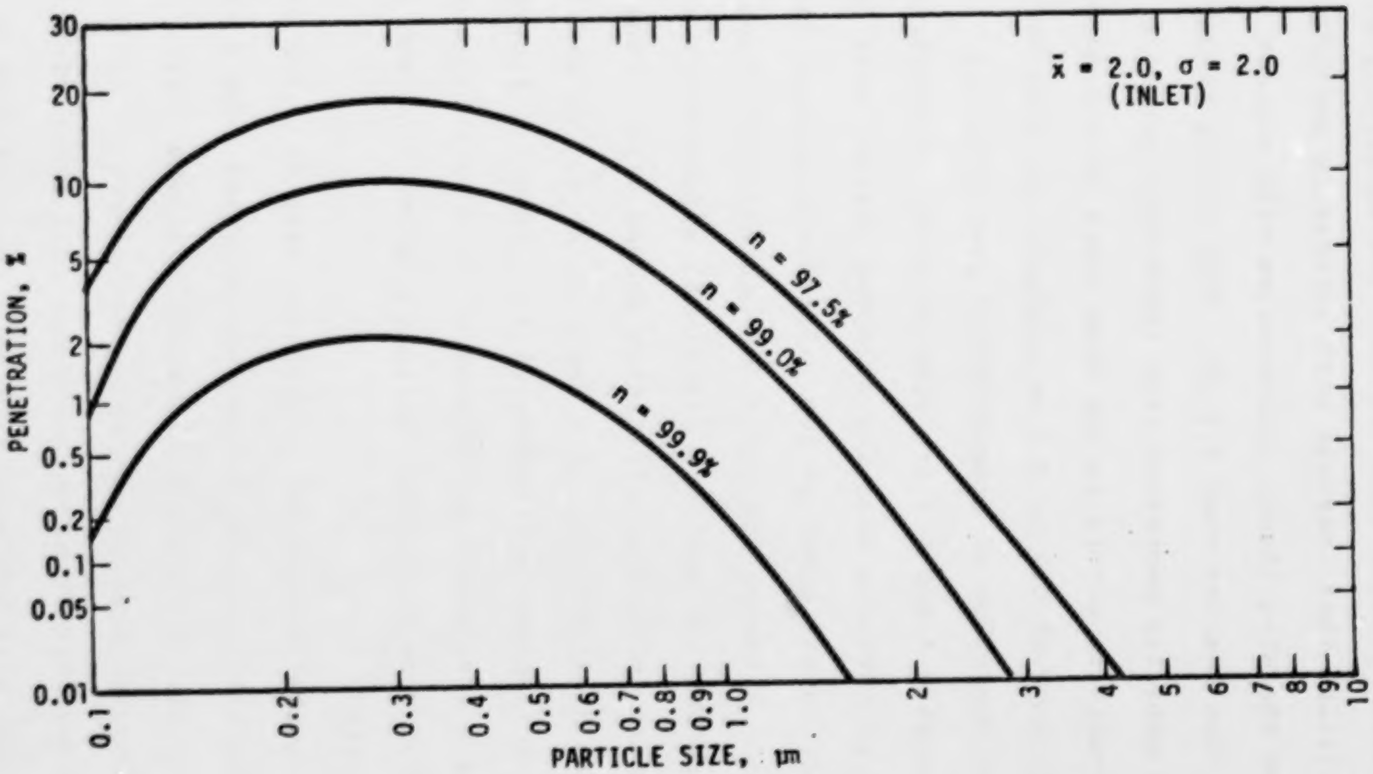

Figure 4-2. Predicted precipitator penetration for conventional and low-odor recovery furnaces.

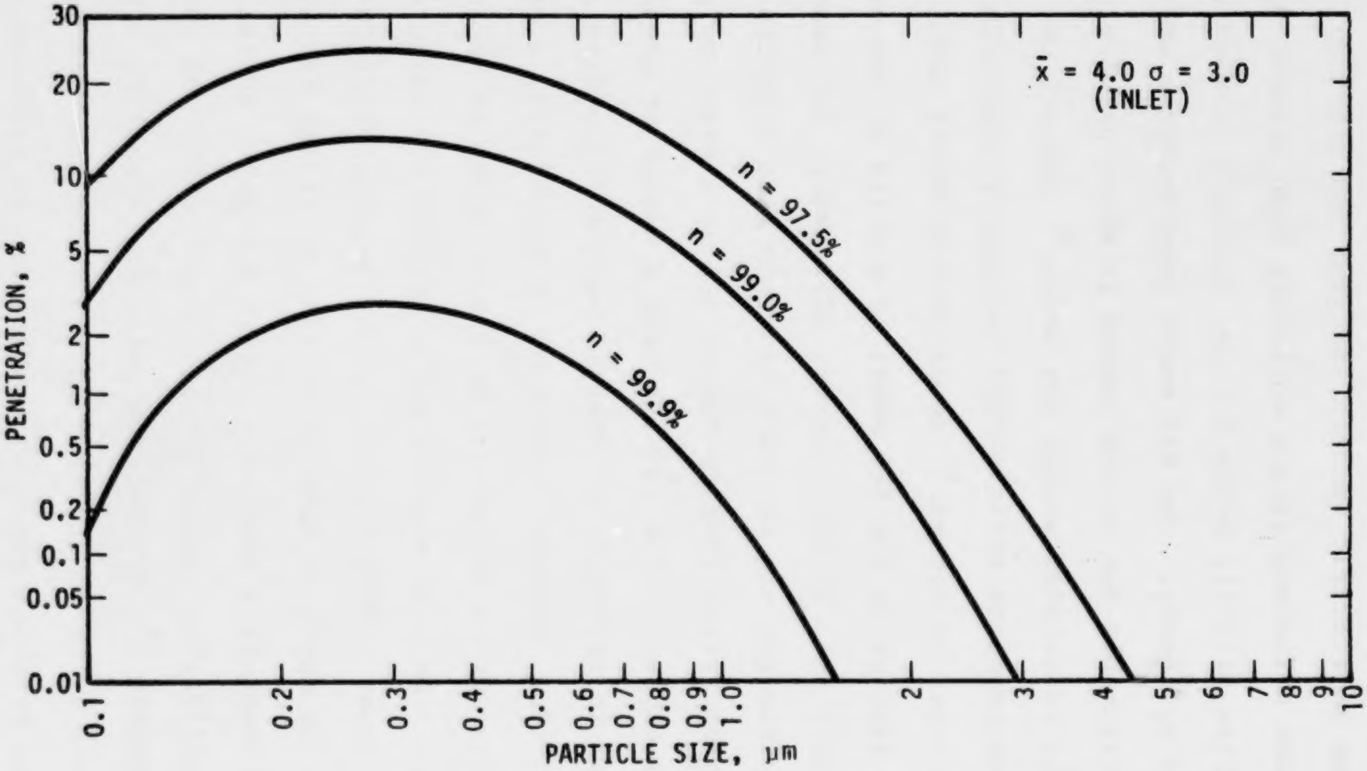

Figure 4-3. Predicted precipitator penetration for conventional and low-odor recovery furnaces.

of the particulate entering the collector was approximately 1 µm. Figure 4-4 presents fractional efficiency results obtained by SRI using an electric aerosol analyzer and inertial impactors. Collection efficiencies are uniformly high between 0.1 and 10 µm, but decline slightly below 0.1 µm, contrary to what would be expected by theory. The SRI model underpredicts efficiency below 1 µm, presumably due to the method in which particulate space charge is calculated within the model.[8] Above 1 µm, the SRI model overpredicts efficiencies because of reentrainment effects on the larger particles.[8] Research-Cottrell's model would show results similar to the SRI model if applied to the same situation. (See Figure 4-1, at 99.9 percent efficiency, for example.)

Another set was obtained from the Fine Particle Emission Information System (FPEIS) for an ESP on a kraft pulp mill recovery boiler.[9] The results from a number of these tests are presented in Figure 4-5. Overall mass efficiencies ranged from 95.89 to 99.34 percent. As shown in Figure 4-5, a minimum efficiency occurs in the 0.2 to 0.4 µm range as would be predicted by theory. Another minimum efficiency is beginning at about 4 µm, the upper reported limit of the impactor test data, presumably due to agglomeration of smaller particles and subsequent reentrainment from rapping. Figure 4-6 shows approximate fractional efficiency curves for two normal ESP's and one with severe reentrainment.[10] The minimum point in collection efficiency for the normal units occurs at 8-10 µm, while the unit with reentrainment problems shows no improvement in efficiency out to a particle size of 100 µm. These curves do not extend far enough

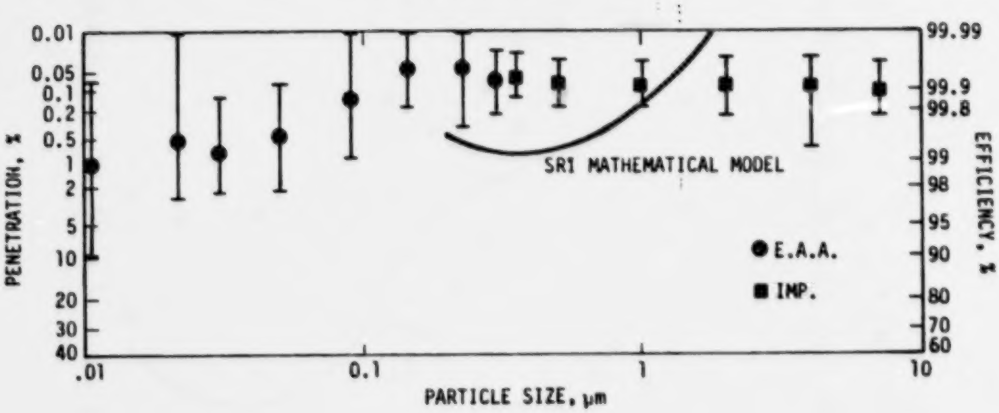

Figure 4-4. Measured and theoretically calculated fractional efficiency of an ESP on a Kraft Pulp Mill recovery boiler.[8]

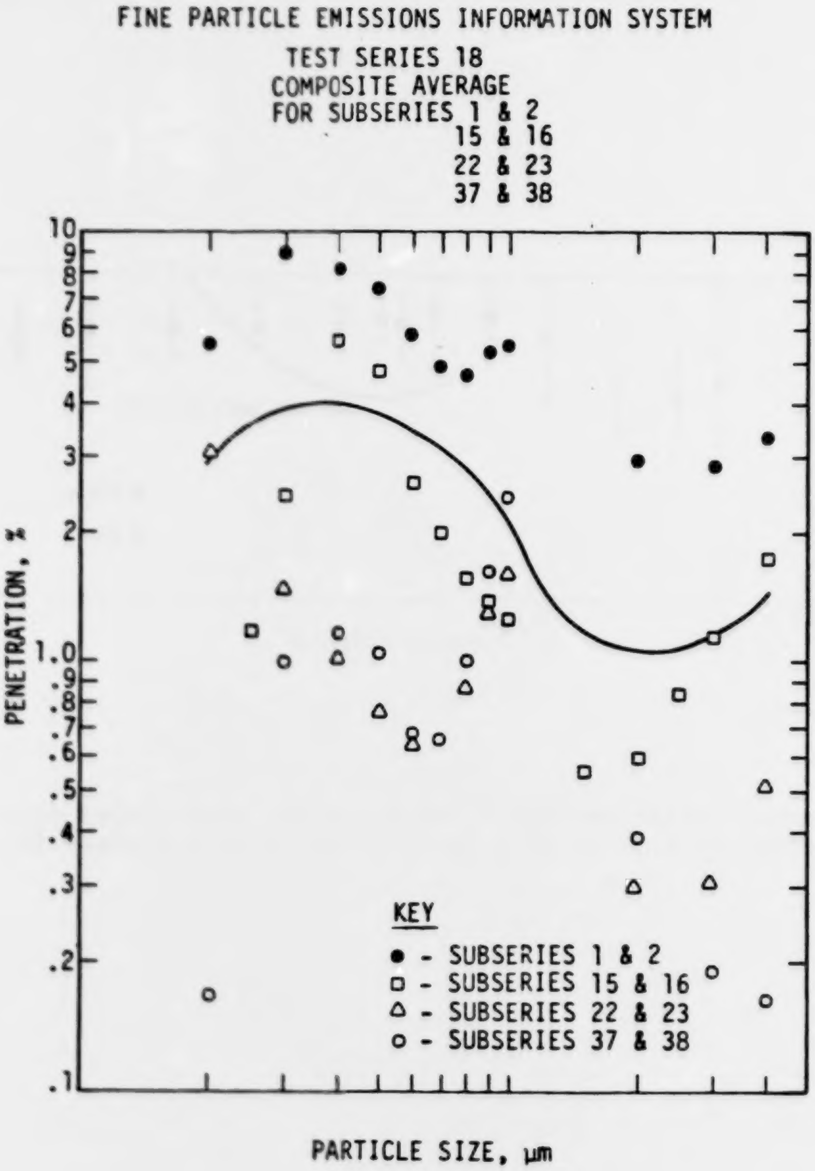

Figure 4-5. Penetration as a function of particle size for an ESP on a kraft pulp mill recovery boiler.[9]

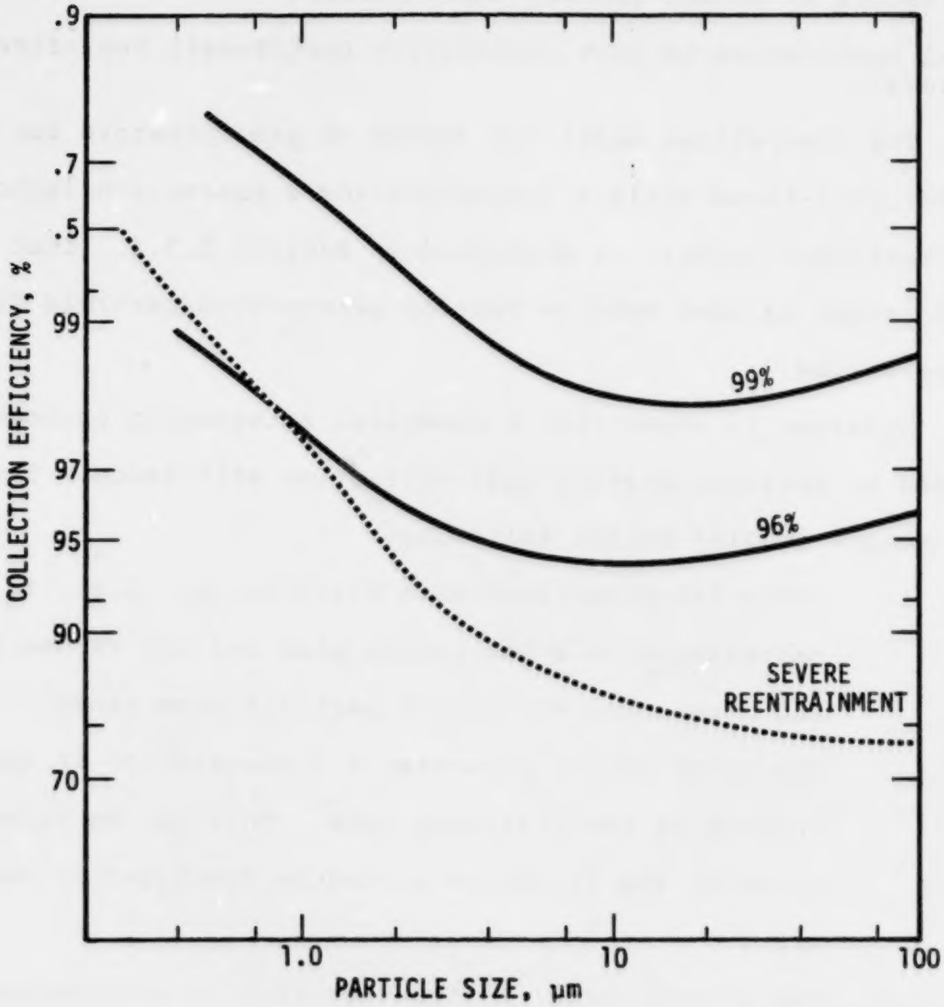

Figure 4-6. Fractional collection efficiency of precipitator collecting particulate from pulp mill recovery boiler.[10]

below 1 μm to determine whether another minimum in collection efficiency occurs in the 0.2 to 0.4 μm range. The minimum in collection efficiency at 8 to 10 μm for the normal units could be the result of normal reentrainment effects.

Model Application to Bark Combination Bark/Fossil Fuel-fired Boilers--

The theoretical model for design of precipitators for bark/ fossil fuel-fired boilers (incorporating a correction factor for reentrainment losses) is described in Section 2.3.2. That formulation is used here to develop penetration/particle size correlations.

Equation 37 shows that a numerical integration procedure is needed to evaluate overall mass collection efficiency. Input parameters consist of the following:

i) Known inlet particle size distribution, i.e., $f_1(d)$, represented by a log normal plot and the values of $\bar{x}$ and σ to cover the entire particle size range.

ii) The value of the parameter K (equation 13) in the absence of reentrainment loss. This can be determined by using the iterative procedure described in Section 4.2.1.

iii) The percent material fraction that is reentrained over the given number of mechanical sections. In equation 36 these variables are r and n.

With values for the above quantities and equation 4 one can estimate percent penetration as a function of particle size.

Precipitators installed on bark-fired and combination-fired boilers usually have four mechanical sections.

Figure 4-7 shows estimated collection performance as a function of particle size at four different levels of particle reentrainment r. Note that the minimum collection is still in the range of 0.2 to 0.4 μm. As r increases, however, the first r-term in equation 36 is predominant relative to the second term, which includes the particle-size-dependent parameter, w_d. As an illustrative example, assume that r is 0.4, i.e. 40 percent reentrainment, and n is 4, i.e. four mechanical sections. In this case the penetrations approach r^4, which is 2.56 percent, irrespective of increasing particle size. Figures 4-8 and 4-9 are similar plots with different assumed inlet distributions. Experimental field test data are needed to support the validity of this formulation.

4.2.2 Wet Scrubber Computer Model

Design Equations and Assumptions--

Venturi scrubbers are well described in the available literature.[11,12] The particle collection process depends mainly upon the acceleration of the gas to provide impaction and intimate contact between the particles and fine liquid droplets generated as a result of gas atomization. The other factor that influences the effectiveness of the venturi scrubber is condensation. If the gas in the reduced-pressure region in the throat is fully saturated, condensation will occur on the particles in the higher-pressure region of the diffuser; this phenomenon, known as heterogeneous nucleation, helps particle growth and also causes agglomeration,

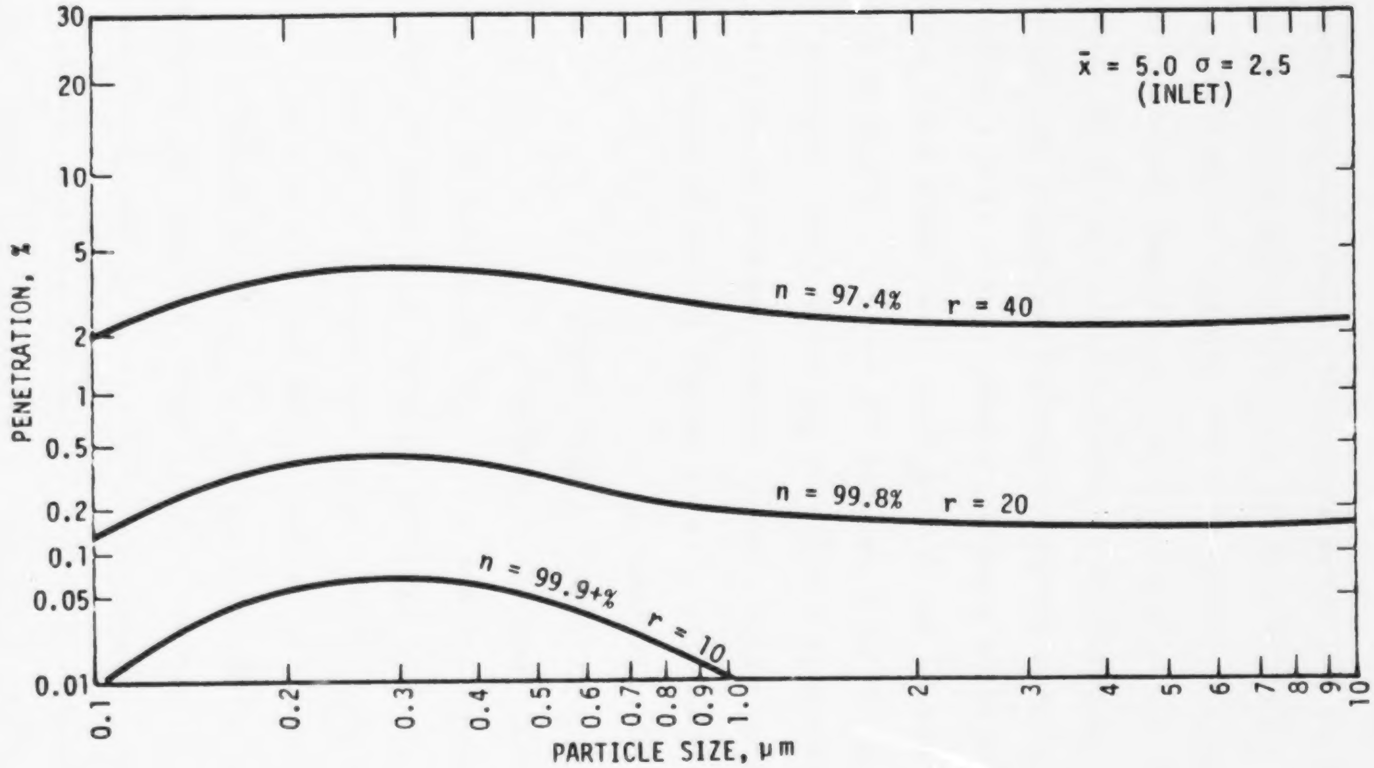

Figure 4-7. Predicted precipitator penetration for bark/ fossil fuel-fired boilers (k = 1.209 x 10^{+4} m^{-1}; n = 4 fields; r = percent reentrainment).

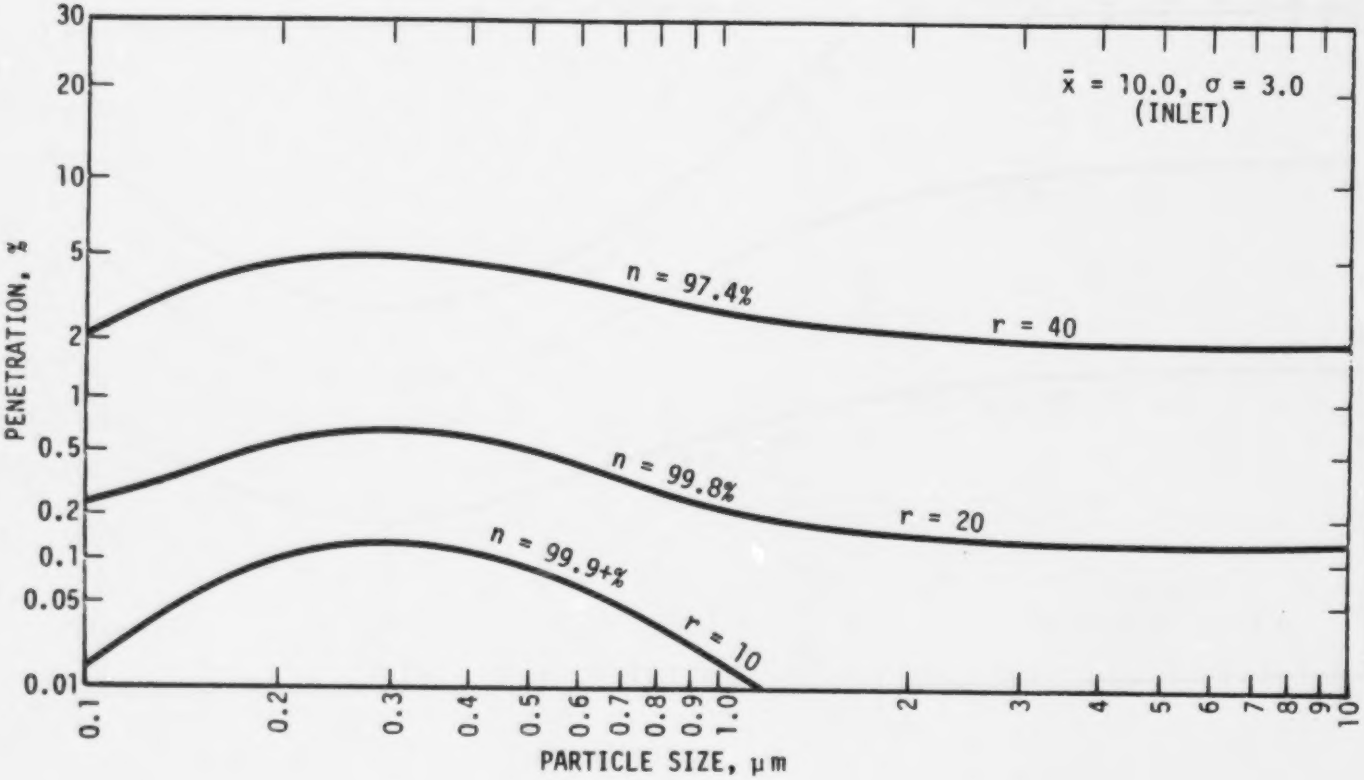

Figure 4-8. Predicted precipitator penetration for bark/ fossil fuel-fired boilers (k = 1.012 x 10^{+4} m^{-1}; n = 4 fields; r = percent reentrainment).

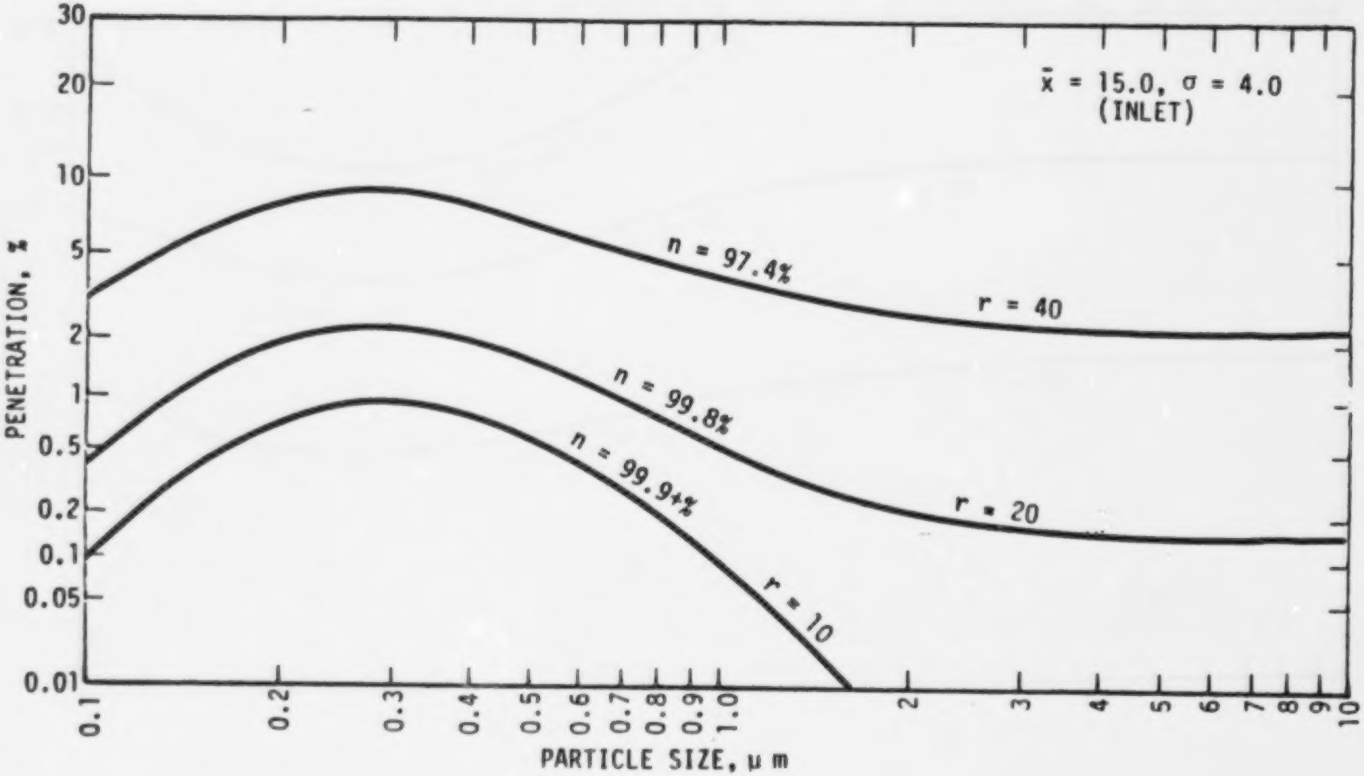

Figure 4-9. Predicted precipitator penetration for bark/fossil fuel-fired boilers (k = 0.6392 x 10^{+4} m^{-4}; n = 4 fields; r = percent reentrainment).

which tends to enhance collection. Detailed particle collection mechanisms in the venturi scrubber have been investigated by many researchers.[13,14,15]

The venturi model used in this study is based on inertial impaction. It is assumed that the particles do not grow during the collection process as a result of heterogeneous nucleation and condensation effects. The general form of the expression for collection efficiency with particle size i can be written as:

$$E_i = 1 - \exp(-K(L/G)\Psi_i) \qquad \text{(Eq. 40)}$$

where E_i = Removal efficiency, fractional

K = Impaction correlational parameter (system parameter)

L/G = Outlet liquid-to-gas ratio, gal/1000 acf

Ψ_i = Inertial impaction parameter of particle size grade, i

Available experimental data have been used to develop a correlation for inlet throat velocity, V_t in ft/s, based on ΔP (in. H_2O) and outlet L/G measurements.

$$V_t = \left[\frac{\Delta P}{5.23 \times 10^{-6}\ (L/G + 105)}\right]^{1/2} \qquad \text{(Eq. 41)}$$

Knowing the inlet throat velocity and measured outlet L/G, one can calculate the droplet diameter from a modified form of an equation developed by Nukiyama and Tanasawa.[15]

$$D_c = \frac{16050}{V_t} + 1.41\ (L/G)^{1.5} \qquad \text{(Eq. 42)}$$

The system parameter, K, is determined by an iterative procedure based on comparison of the actual measured overall mass collection efficiency and that calculated from summing the individual fractional efficiencies. For a given particle size the inertial impaction parameter is defined below:

$$\Psi_i = \frac{0.85(C)\ (\rho_p)\ (D_p)^2}{\mu}\ \frac{V_t}{D_c} \qquad \text{(Eq. 43)}$$

where C = Cunningham correction coefficient

ρ_p = Particle specific gravity, g/cm^3

D_p = Particle diameter, μm

μ = Dynamic gas viscosity, poise x 10^4

D_c = Droplet diameter, μm

and

$$C = 1 + \frac{2\lambda}{D_p}\ 1.23 + 0.41\ \exp(-0.44\ \frac{D_p}{\lambda}) \qquad \text{(Eq. 44)}$$

The value of K is modified during the course of iteration to yield a closer match between measured and calculated overall mass collection efficiencies for given input values of L/G and ΔP. When the "optimum" value of K has been found, it is inserted into the above equations to generate the outlet particle size distribution and finally the fractional penetration for the various particle sizes. This is really an averaged system parameter, since it is not a function of any specific particle size.

Penetration as a Function of Particle Size--

Figure 4-10 shows penetration as a function of particle size for venturi scrubbers collecting sludge lime kiln dust. Typical ranges of operating parameters were taken from general literature, and the inlet particle size distribution was derived from data presented by Cheremisinoff,[5] who does not mention how much soda fume (Na_2O) is present. Since these particles are generally

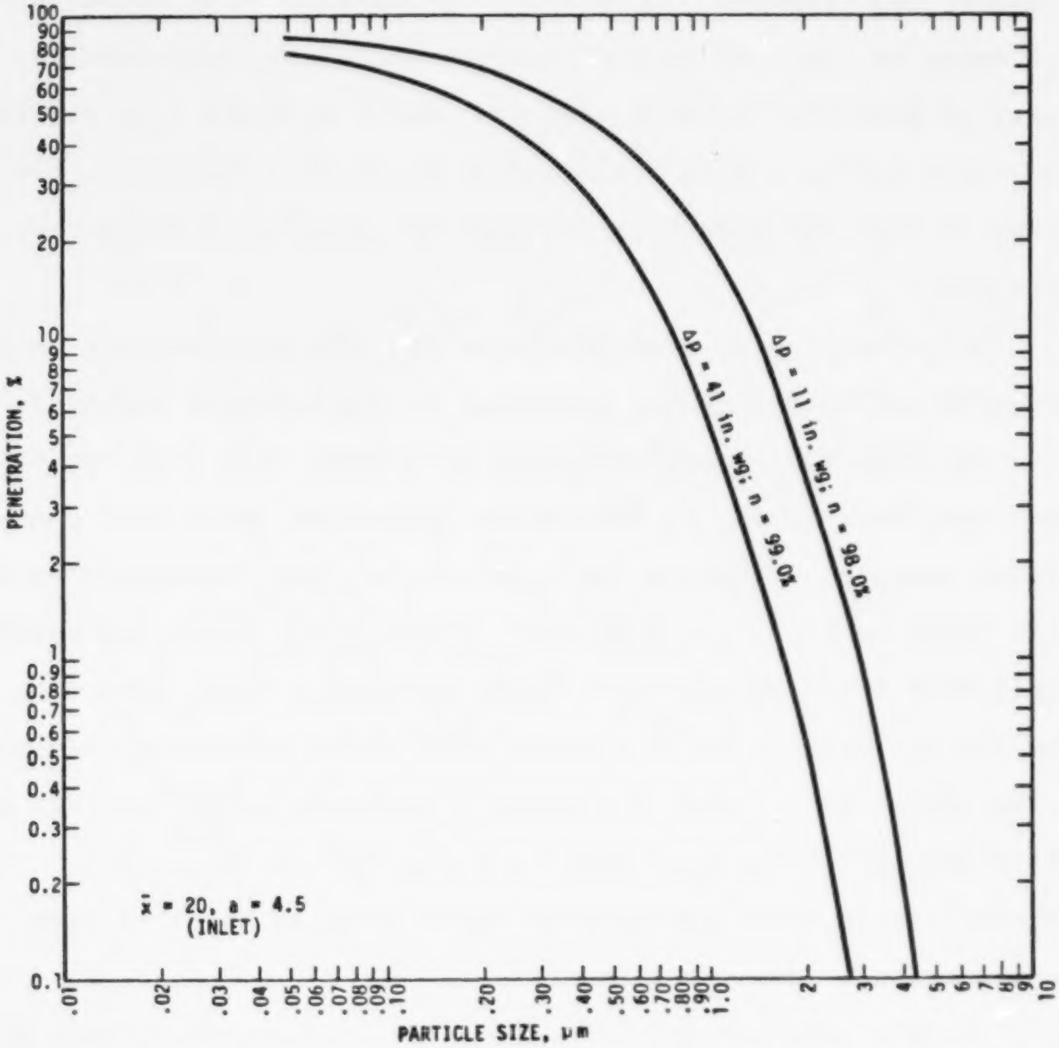

Figure 4-10. Predicted penetration for venturi scrubbers on sludge lime kilns, L/G = 15.

considerably less than 1 μm and constitute up to 2 percent of a typical unburned lime,[16] they can significantly raise scrubber pressure requirements. Pressure drops substantially above 20 in. H_2O would be required to achieve mass collection efficiencies above 99 percent. In this case the use of an $\bar{x}$ and σ to specify the inlet particle size distribution is somewhat deceiving because it does not adequately reflect the preponderance of fine particles.

Computer-predicted penetrations for venturi scrubbers on jaw crushers and conveyors are presented in Figures 4-11 and 4-12.

The only available fractional efficiency test data for venturi scrubbers on any of the subject processes comes from unpublished impactor test data for a venturi scrubber operating on a salt laden bark/oil fired boiler. Although the inlet and outlet tests were taken on different days, the boiler conditions were similar for both tests, and so an approximate fractional efficiency curve was prepared, and is presented in Figure 4-13. Overall mass efficiency for these test data is approximately 68 percent. The characteristic sharp increase in penetration as particle size decreases is evident in this cruve.

Overall mass and some fractional efficiency pilot tests on hogged fuel boilers have been conducted with novel type electrostatic scrubbers. The TRW charged droplet scrubber, the Ceilcote ionized wet scrubber, the APS electrostatic scrubber, and the University of Washington electrostatic scrubber are the novel type electrostatic scrubbers which have been tested. Table 4-2 compares characteristics and performance of these electrostatic

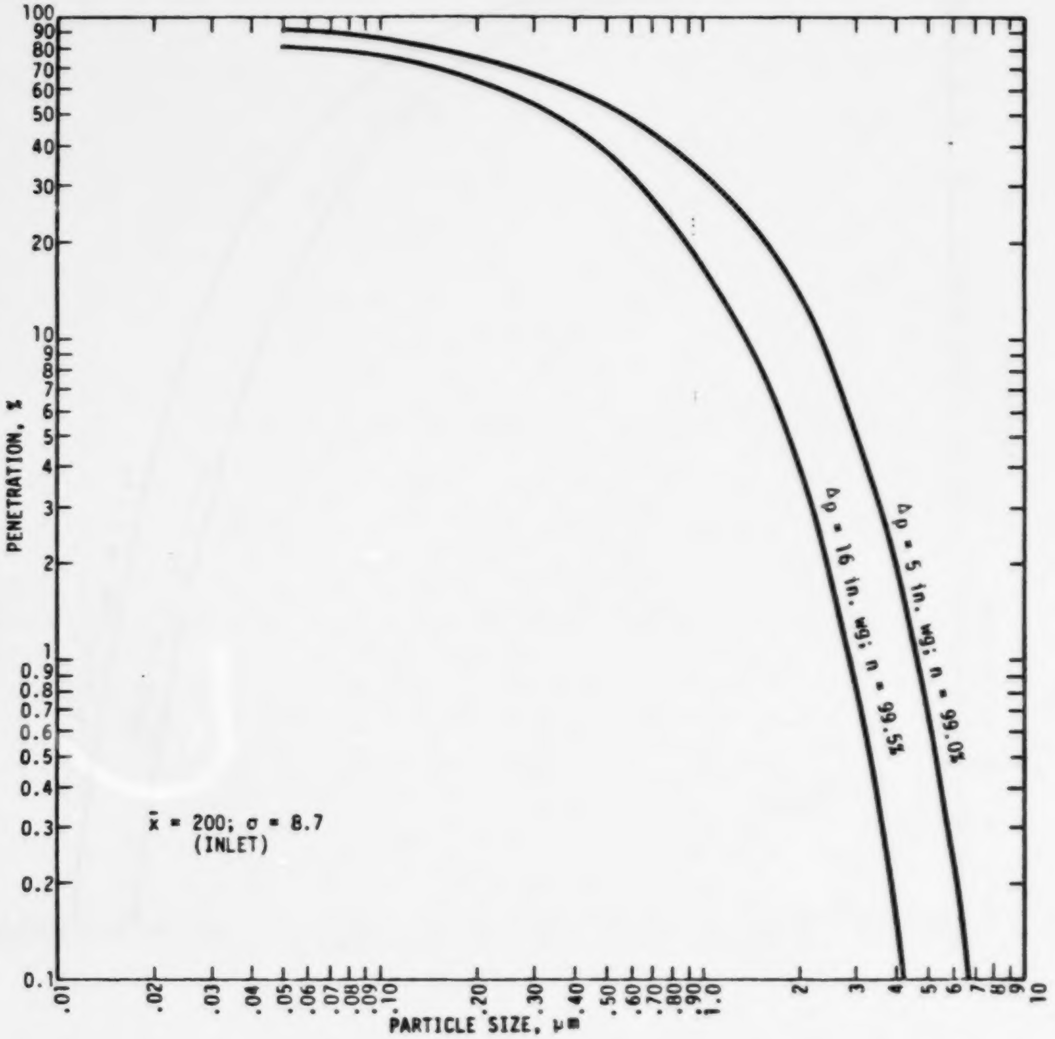

Figure 4-11. Predicted penetration for venturi scrubbers on jaw crushers; L/G = 5.

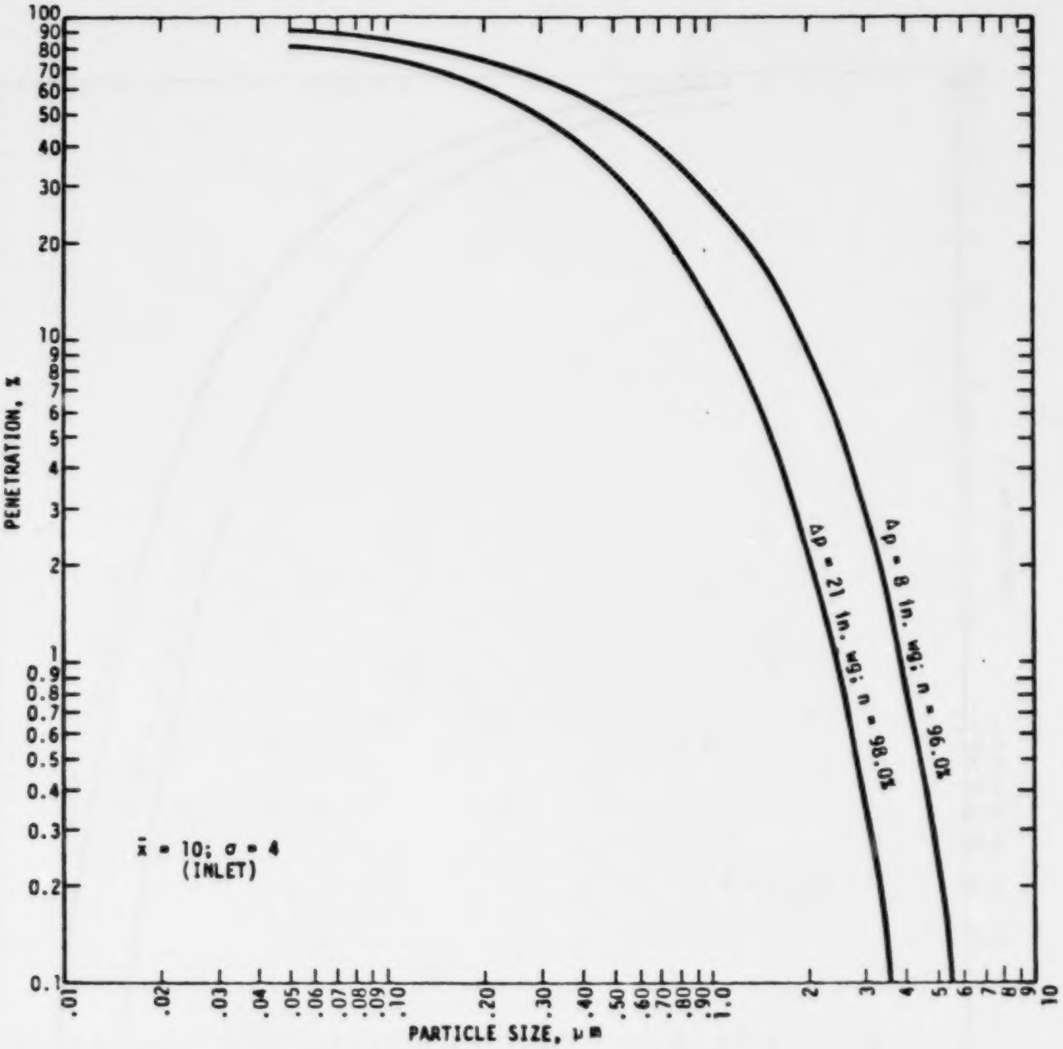

Figure 4-12. Predicted penetration for venturi scrubbers on conveyors and screens; L/G = 5.

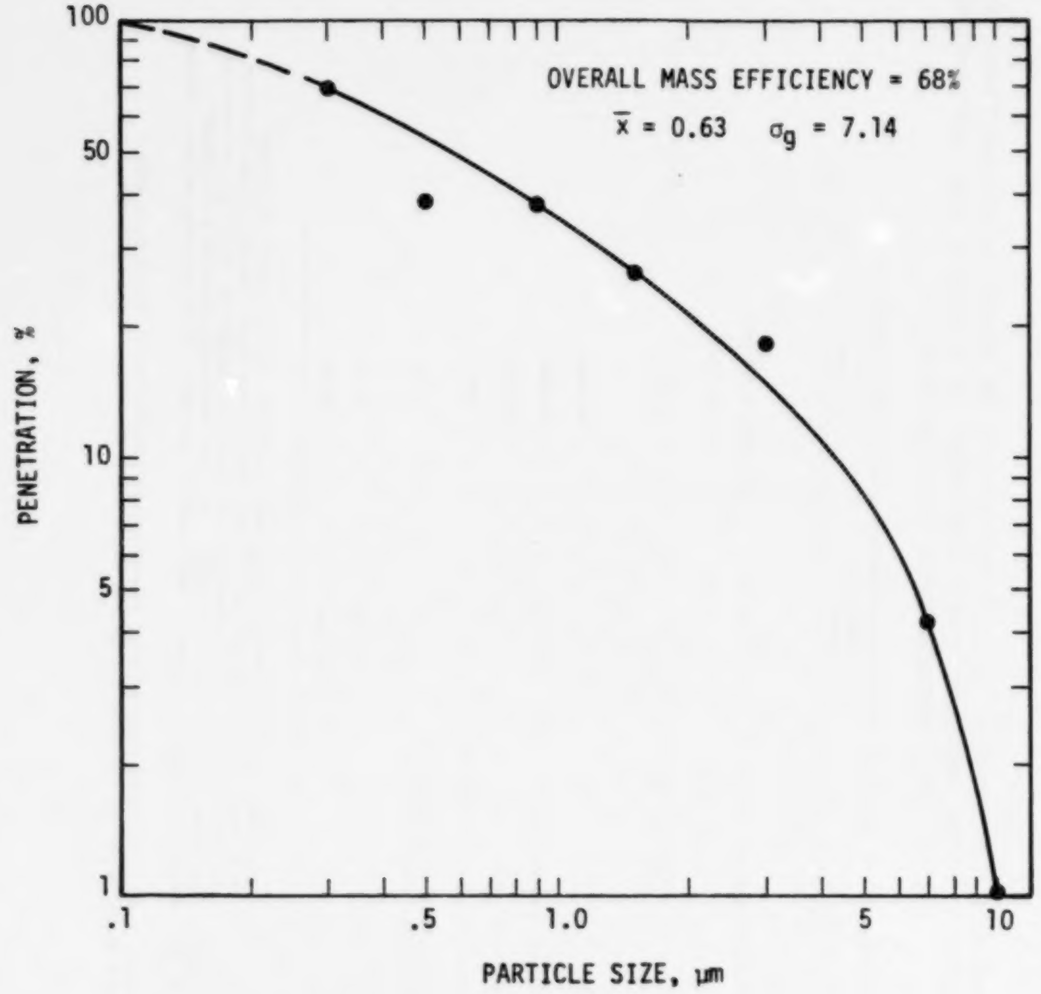

Figure 4-13. Approximate penetration as a function of particule size for a venturi scrubber operating on a salt-laden bark/oil fired boiler.

TABLE 4-2. COMPARISON OF TYPICAL CHARACTERISTICS OF NOVEL ELECTROSTATIC TYPE SCRUBBER WITH CONVENTIONAL VENTURI TYPE SCRUBBER IN GENERAL AND APPLIED TO SALT LADEN HOGGED FUEL BOILERS[18,19]

Characteristic	Electrostatic scrubber	Venturi scrubber
1) Specific to salt laden hogged fuel boilers		
• Overall mass efficiency %	high (95-99+)	medium (60-80)
• Pressure drop, in. H_2O	low (0.3-2)	medium (20)
• Capability for collecting fine particles (<2 μm)	high[a]	low[b]
2) General		
• Initial cost	high	medium
• Energy consumption	low	medium
• Operating cost	low	medium
• Liquid clarity requirements	low	low
• Adoptability to corrosion resistant construction	low	high
• Operating full scale experience	medium	high
• Reliability	medium	high

[a] Reported from pilot tests on salt laden hogged fuel boilers: 1) Ceilcote two stage IWS - 94.6 to 99.5% overall efficiency; 70% of particulate was NaCl; 80-95% of particulate was <0.4 μm; size distribution almost identical at inlet and outlet of IWS. 2) University of Washington two stage electrostatic scrubber. 3) Air Pollution Systems Electrotube: 95.6 to 99% removal efficiency; 35-80% of particulate was NaCl; 30-35 percent of particulate was <1 μm.

[b] See Figure 4-13. Pressure drop at this installation limited to 20 in. H_2O; higher pressure drops would be required for better collection of particle sizes <2 μm.

scrubbers with a conventional venturi scrubber operating on a salt-laden bark/oil fired boiler at a 20 in. H_2O pressure drop.

4.3 EFFICIENCY RELATIONSHIPS FOR FABRIC FILTERS

It would be desirable to characterize baghouse collection efficiency as a function of particle size for the processes discussed. However, manufacturers seldom base baghouse guarantees on fractional collection efficiency. They prefer overall collection efficiency or outlet concentration guarantees based on their past experience with the same or a similar type of process. There is little incentive for manufacturers to relate baghouse performance to particle size on existing systems and as a result, this information is practically nonexistent. Even though fractional efficiency data for baghouses in the kraft pulp and crushed stone industries are lacking, there is adequate evidence in the literature from other industries to document the fact that fabric filters preserve good fractional efficiency of filtration in the submicron particle size range. In other words, unlike scrubbers and ESP's fabric filters preserve high collection efficiency for the small particle size ranges without any modification to their design or operation.

It must be pointed out, however, that there are several subtleties reported in the literature regarding the actual shape of the fractional efficiency curve for a fabric filter. There are reports suggesting that the collection efficiency of a fabric filter tends to drop somewhat in the submicron particle size range particularly in the 0.2 to 0.4 μm region. This behavior is also common to scrubbers and ESP's except that in their case the drop in efficiency is more pronounced. In one recent report,[20] it is postulated that mechanisms during high velocity filtration can actually lead to decreased filtration efficiency on larger particles. The three mechanisms are as follows:

1. Straight Through Penetration: Immediately after cleaning, many particles collect upon the exposed fibers. Soon, however, a continuous dust deposit forms on the fabric surface and particles collect upon previously deposited dust. Particles not collected by the filter, but which pass through without stopping penetrate the filter by the "straight through" mechanism.
2. Seepage: Once a particle lands on or in the fabric, it need not necessarily remain at its point of initial impact. As the dust deposit builds up, pressure drop can increase to several times its initial value. Meanwhile, the fabric substrate may stretch, allowing some previously collected particles to work through. Filter behavior of this sort is "seepage."
3. Pinhole Plug: Small diameter pinholes occur at the surface of dust deposit on woven fabrics. Similar holes on a needle-punched felt may correspond to the places where needles penetrated the cloth during its manufacture. A plug of deposited particles may dislodge from the dust deposit and pass through the fabric all at once as the supporting fibers move and stretch

beneath it, leaving behind such a pinhole. Particles which pass through the filter in this way do so by a "pinhole plug" mechanism.

Therefore, particles can pass through the filter by the "straight through" mechanism without being stopped, whereas previously collected particles can make their way through by the "seepage" and "pinhole plug" mechanisms. In addition, the fraction of the total fabric filter penetration represented by "pinhole plugs" can be as high as 70 percent. This could account for the presence of large particles on the outlet side of baghouses in amounts not expected by considering classical filtration theory.

One set of fractional efficiency test data was obtained from the FPEIS[21] for U.S. EPA's mobile fabric filter applied to a lime kiln at a kraft pulp mill. Results from a number of these tests are presented in Figure 4-14. Overall mass efficiencies were above 99.9 percent. Penetration in the 0.4 to 10 μm range is less than 1 percent. A minimum efficiency occurs at approximately 0.8 to 1.0 μm.

None of the plants contacted during this study could provide fractional efficiency information. In fact, many of the crushed stone installations did not ever have total mass efficiency data since their control systems had never been tested for verification of the manufacturer's efficiency claim. Therefore, the subsequent discussion is limited to a review of reported overall efficiencies in the two subject industries.

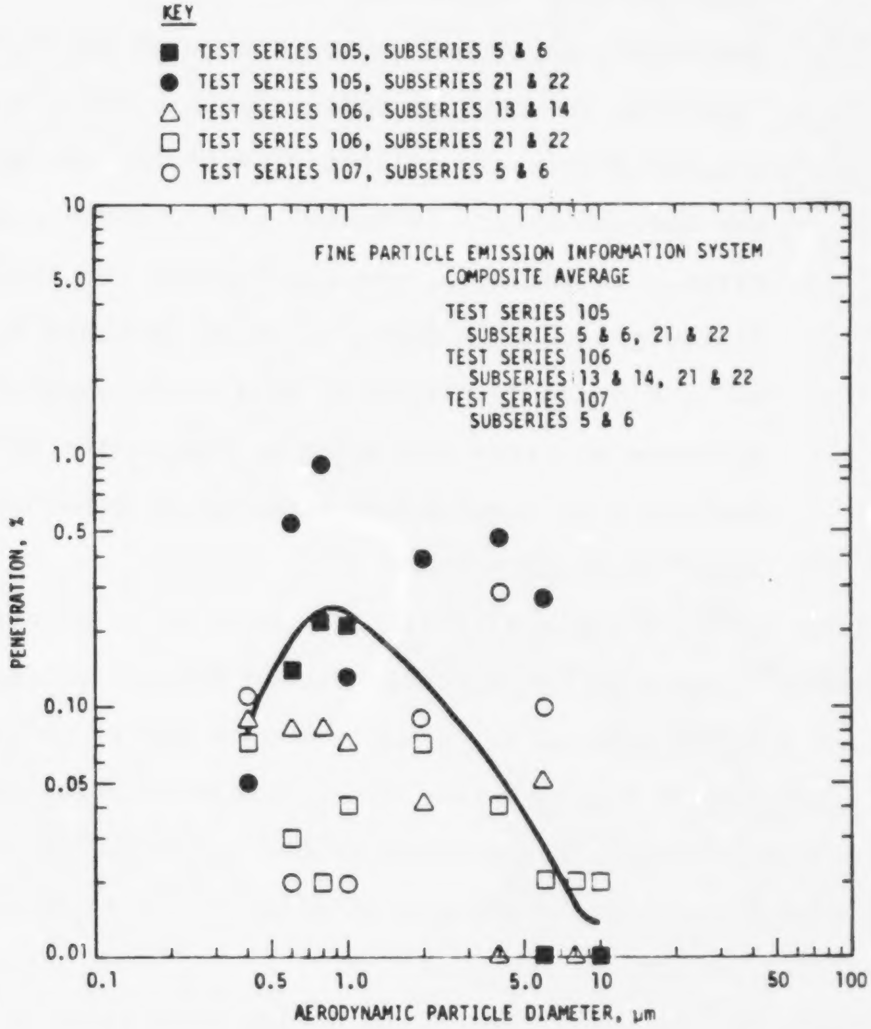

Figure 4-14. Penetration as a function of particle size for a mobile fabric filter on a kraft pulp mill lime kiln.[17]

4.3.1 Bark-Fired Power Boilers in the Kraft Pulp Industry

Neither of the two pulp mills contacted had fractional efficiency information for the baghouses servicing their bark-fired boilers. The overall mass efficiency, however, is reported to range from 90 to 95 percent in one unit with outlet loadings of 0.01 and 0.04 gr/scf adjusted to 12 percent CO_2. This lower than normally expected efficiency for a fabric filter assumes that a certain number of the bags are always leaking or broken. The other facility reports an efficiency of 99.0 percent. Because the logs used in the former pulp mill are stored in seawater, the particulate emissions from the bark boilers contain a high percentage of sodium chloride. These particles are generally in the submicron range and contribute to atmospheric haze. The plant personnel at this firm reported that the primary reason for installing baghouses on both boilers was to reduce the emission of submicron particles. After installation of the baghouses, the boilers have been effectively meeting the applicable opacity regulations, suggesting that these fabric filters are efficient collectors for submicron particles. The reported overall efficiencies of 99 percent fromthe latter non-salt facility or higher are typical of fabric filters in general, and this same level of efficiency could be extrapolated to other bark boilers.

4.3.2 Crushed Stone Operations

Again, very little data are available on actual efficiencies of baghouses servicing stone crushing operations. There have been no known fractional efficiency tests reported in the literature. The majority of emission tests report only the effectiveness of the dust control system regarding compliance with local emission regulations. Table 4-3 presents the overall mass efficiency data for baghouses installed at a crushed stone plant. These data are taken from emission test results reported in the literature.

Table 4-4 presents data on overall collection efficiencies of fabric filters at plants contacted during the course of this study. It also includes the efficiencies of baghouses at two crushed stone plants visisted during the study. These are indicated as Plants 5 and 6.

Table 4-3. BAGHOUSE PARTICULATE CONTROL EFFICIENCIES ON CRUSHED STONE INDUSTRY PROCESSES

Dust source	Inlet concentration, gr/dscf	Outlet concentration, gr/dscf	Overall mass efficiency, %
Primary crusher[a]	5.633	0.009	99.84
Primary crusher, scalping screen, hammermill, etc.[b]	1.455	0.00185	99.87
Sizing screens[c]	0.192	0.003	98.44

[a] Data are average of three tests. Reference - Air Pollution Emission Test, Kentucky Stone, Russelville, Kentucky, Office of Air and Waste Management, Contract No. 68-02-1406 (1975).

[b] Data are average of two tests. Reference - Air Pollution Emission Test, J.M. Banner Company, Lancaster, Pennsylvania, Office of Air and Waste Management, Contract No. 68-02-1408 (1975).

[c] Data are average of two tests. Inlet loading data are reported to be of questionable validity. Reference same as b.

Table 4-4. BAGHOUSE PARTICULATE EFFICIENCIES - SURVEY DATA

Plant number	Dust source	Overall mass efficiency, %
1	NA	99.0
2	Five stone crushers	99.88
3	Ten pickup points including crushers, impactors, belts, etc.	99.0
4	Stone dryer	≈ 100.0
5	Stone crushing, screening, and conveying	99+
6	Fine grinding Secondary crushing and screening Storage silos	99.0 99.9 99.8-99.9

NA = Information not available.

The above data indicate that baghouses servicing stone-crushing operations have an average overall efficiency in excess of 99 percent by weight. This high efficiency is in part a result of the coarse nature of dust emitted from stone crushing operations.

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SECTION 5

SUMMARY AND CONCLUSIONS

This report reviews the use of conventional control devices (ESP's, scrubbers, and fabric filters) for limiting particulate emissions from kraft pulp mill and crushed stone industry processes. Principal areas of study are: important design parameters, operation and maintenance procedures, and fractional efficiency capability of each control device. The following sections summarize the report and present conclusions drawn from each area of study.

5.1 DESIGN PARAMETERS

In evaluation of alternative methods of particulate control for each of the subject processes, it became clear that one type of control device usually predominated. For example, nearly all kraft recovery boilers are controlled with ESP's. Some scrubbers have been installed on U.S. kraft recovery boilers, but only as retrofit controls. Smelt dissolving tanks are controlled by low-energy scrubbers, and lime kilns, almost exclusively by venturi scrubbers. One U.S. mill has retrofitted an ESP to serve three existing kilns.

Combination bark/fossil-fuel boilers are an exception, in that ESP's, scrubbers, and fabric filters all have been used for control of particulate emissions. Use of these devices is relatively new and until recently bark/fossil-fuel boilers were controlled with mechanical collectors. Where hogged fuel contains salt accumulated during transport by sea, the fine salt particles can cause excessive opacity of the plume. In these circumstances only venturi scrubbers and fabric filters have been used for particulate control. Presumably since ESP manufacturers will guarantee meeting transmissometer opacity but not visible opacity regulations when salt-laden fuel is burned, no ESP's have been installed on bark boilers with a salt emission problem.

In the crushed stone industry, fabric filters are preferred for control at point sources. Wet suppression is also used alone and in conjunction with fabric filters, and low-energy venturi scrubbers have been used on conveying and crushing processes. High-energy venturi scrubbers would provide better performance, but none are presently in use.

General advantages and disadvantages of applying ESP's, scrubbers, and fabric filters to the subject processes are presented in Tables 5-1 through 5-3.

ESP's

The use of ESP's on conventional and low-odor recovery boilers and on bark/fossil-fuel boilers was evaluated. Differences in ESP design for use on conventional and low-odor boilers are attributed to differences in temperature, bulk density, tenacity of dust, and SO_2 content. The particle size distributions in effluents of conventional and low-odor boilers are

Table 5-1. EVALUATION OF DRY ESP'S FOR KRAFT PULP MILL RECOVERY BOILERS AND BARK/FOSSIL-FUEL BOILERS

Advantages	Disadvantages
Can be designed to provide high collection efficiency for all sizes of particles from submicron to the largest; new designs can meet stringent particulate regulations	Low resistivity of process dust causes re-entrainment problems
Economical operation because of low internal power requirements and inherently low draft loss; high reliability	Rapper failure, discharge wire breakage; ash hopper plugging and corrosion are potential maintenance problems
Flexible in gas temperature, ranging from as low as 200°F to as high as 800°F	Efficiency sensitive to change in dust characteristics; visible opacity problems with salt-laden bark ash
Long useful life if properly maintained	Potential for explosion and fire during startup because of high-voltage sparking; also because of unburned carbon from bark boilers
No water pollution potential	High-voltage hazards to personnel
Extensive history of application on recovery boilers	

Table 5-2. EVALUATION OF VENTURI SCRUBBERS FOR KRAFT PULP MILL LIME KILNS AND CRUSHED STONE PROCESSES

Advantages	Disadvantages
Smaller space requirements than precipitator or fabric filter	Collection efficiency decreases rapidly with decreasing particle size
Not affected by high-resistivity process dust; relatively insensitive to chemical composition and variations in gas temperature	Maintenance costs higher than with ESP'S and fabric filters because of corrosion, scaling, plugging
No high-voltage hazard	Water pollution control required for scrubber effluent; performance dependent on quality of recycled water
Less heat loss on lime kilns than with ESP	High pressure drop and resulting higher power demand needed for high efficiency

Table 5-3. EVALUATION OF FABRIC FILTERS FOR KRAFT PULP MILL BARK/FOSSIL-FUEL BOILERS AND CRUSHED STONE PROCESSES

Advantages	Disadvantages
Collection efficiency essentially independent of chemical content of dust	Higher pressure drop than ESP leading to higher energy consumption
High overall mass and fractional efficiency (99+%)	Fabric life is uncertain; may be shortened in the pressence of acid or alkaline particles fluorides
Collection efficiency and pressure drop relatively unaffected by changes in inlet grain loadings with continuously cleaned filters	Space requirements usually greater than for ESP'S or scrubbers, except at high A/C ratios
No water pollution potential	Condensation of moisture may cause crusty deposits or plugging of fabric; may require special additives
No corrosion problem	Fires can occur in bark boilers if mechanical collector is not used as spark arrestor preceding fabric filter
No high-voltage hazard, thus simpler maintenance	

similar, and resistivity of both process dusts is around 10^9 ohm-cm.

Because of higher SO_2 levels, the dust from low-odor boilers adheres very tenaciously to the collecting plates and necessitates heavy rapping. This vigorous rapping, combined with the lower bulk density of the low-odor boiler dust, leads to higher re-entrainment of particles. Moreover, the higher viscosity of the low-odor boiler dust (due to its temperature) increases the drag force on the dust particles. Because of these factors, the SCA requirement for an ESP on a low-odor boiler is about 15 percent greater than with a conventional boiler. Additional test data are needed to verify this finding. In any event the design SCA's for high-efficiency (99.5% or greater) ESP's on kraft pulp mill recovery boilers should be in the range of 380 to 450 ft^2/1000 acfm.

The low resistivity (10^7- 10^9 ohm-cm) of the bark ash causes serious problems of re-entrainment for ESP's. A correction factor that assumes a constant rate of re-entrainment in each mechanical section of the ESP is applied to the modified Deutsch design equation for SCA, and accounts for this high rate of re-entrainment. Thus in a high-efficiency ESP application (99.5% for example) on a bark/fossil-fuel boiler, SCA requirements would range from approximately 380 to 500 ft^2/1000 acfm assuming 40 to 50 percent re-entrainment of the bark ash. Where firing of bark would cause a salt emissions problem, the SCA requirements would be higher because of the smaller size of salt particles.

Wet Scrubbers

Emphasis in this study is on venturi scrubbers because their particulate removal efficiencies are higher than those of impingement type scrubbers, mesh demisters or packed towers. Newer lime kiln installations use venturi instead of impingement scrubbers. Most smelt dissolving tanks use mesh demisters and/or packed towers to collect particulate from exhaust gases. Venturi scrubbers are used successfully on bark/fossil-fuel boilers.

Design requirements for venturi scrubbers for kraft pulp mill applications (lime kilns and bark/fossil-fuel boilers) include pressure drops in the range of 10 to 20 in. H_2O and L/G's of 10 to 15 gal/1000 acf to achieve collection efficiencies of 90 to 95 percent.

The effect of particle size on performance of venturi scrubbers is evident in data from two recent scrubber installations on bark/oil-fired boilers, one with a salt emissions problem. Because of the small particle size of the salt, the scrubber on the boiler burning salty fuels requires a 15 to 20 in. H_2O pressure drop to obtain outlet emissions at 0.07 to 0.18 gr/dscf depending on the salt content of the fuel. In contrast, the other operates at 8 to 10 in. H_2O yielding outlet emissions of 0.02 gr/dscf.

In crushed stone applications of wet scrubbers, since the particles emitted from crushers are larger than those from conveyors, again a lower pressure drop in the crusher scrubbers will yield higher collection efficiency. Design requirements from

Research Cottrell's computer model estimates for crusher applications are 5 to 16 in. H_2O pressure drop to achieve for 99.0 to 99.5 percent efficiency at an L/G of 5 gal/1000 acf. For conveyor applications these requirements increase to 8 to 21 in. H_2O pressure drop to achieve 96 to 98 percent efficiency at an L/G of 5 gal/ 1000 acf.

Fabric Filters

Design A/C ratios for fabric filters presently installed on bark/fossil-fuel fired boilers range from 4 to 5:1. The presence of fines in the bark mix prevents operation at higher A/C ratio because of excessive pressure drops. As an example, the Simpson Timber Co. baghouse collects ash from salt-laden bark, with a particle size distribution skewed largely toward the submicron range. The average operating pressure drop at 10 in. H_2O is 3 in. H_2O over the design value. The A/C ratio is probably slightly high at 4:8 to 1. In two other baghouses on bark/fossil-fuel boilers with no salt emission problem the A/C ratios are 4:1. In all three installations the use of pulse jet cleaning allows for slightly smaller collectors by the increase in A/C ratio. Use of a mechanical collector preceding the baghouse is mandatory to collect hot cinders that could cause fire.

In the crushed stone industry the baghouse is likely to remain as the preferred control device because the dry, inert dust often can be used as a stone product or recycled within the plant. Particles from the various crushed stone processes are coarse enough that A/C ratios as high as 7.5:1 are used in conjunction with pulse jet cleaning. Shaker cleaning with A/C ratios of 2 to 3:1 is also popular. Pressure drops from respondents in this study range from 2 to 8 in. H_2O; the finer particles from tertiary crushing and screening cause the higher pressure drops.

In both industries studied, and in most applications, fabric filter operation is relatively insensitive to process variables such as chemical composition, particle size, and resistivity, although chemical composition of particles can critically affect fabric selection.

5.2 OPERATION AND MAINTENANCE

The more stringent emission standards of recent years require that a company follow a program of regular maintenance of control devices to remain in compliance. The high cost of particulate control equipment also justifies a high priority on maintenance.

5.2.1 ESP's

Maintenance of ESP's in the kraft pulp mill industry is apparently more difficult than in utility or metallurgical applications. On recovery furnaces the most common operating problems are corrosion and failure of rappers. Other problems result from drag bottom conveyors, plugging of the inlet distribution plate, buildup on ladder vanes, and "snowing" or intermittent puffing of recovery furnace stacks. Effluent from low-odor boilers cause more problems than that from conventional boilers because of the light, fluffy dust and the high SO_2

content, often causing corrosion. In this application, the performance of an ESP can deteriorate with time.

Because ESP's are rarely used on bark/fossil-fuel boilers, little information is available on operation and maintenance.

5.2.2 Scrubbers

With regard to the venturi scrubber, general operational problems on kraft pulp mill and crushed stone processes parallel those in other utility and industrial applications. They chiefly involve corrosion, plugging, and abrasion.

Several operators of sludge lime kilns report low maintenance and minimal operator attention with venturi scrubbers. However, in these installations, fresh water should be used instead of contaminated condensate to minimize odorous emissions from stripping.

On bark boilers, the performance of a venturi scrubbers is greatly affected by the quality of the water used. The requirement for "bleed-off" of dissolved solids may become difficult because of increasing limits on water discharge.

No data are available on operation and maintenance of venturi scrubbers on crushers and conveyors in the crushed stone industry.

5.2.3 Fabric Filters

According to respondents in this study, fabric filters provide reliable service on crushed stone processes, although maintenance data are sketchy. Major problems are related to the cleaning mechanism and dust removal system. Failures of valves and diaphrams, air compressor bearings and drive belts, and solid-state circuits associated with the pulse jet cleaning mechanism have caused difficulties. Bridging of hoppers and breakage of screw conveyor shafts by overloading are the two most common problems in dust removal and conveying systems.

Data from Simpson Timber Co. indicate that overall operation has been satisfactory; problems center on the collection hoppers, where the light dust causes plugging. The dust contains salt and tends to bridge the hoppers. Vibrators have been used successfully to relieve the plugging. No reliable sensing system to detect plugging has been devised.

Data on the effects of various control device malfunctions on performance of equipment are not available. It can be stated generally that without regular maintenance the performance of these control devices will degrade rapidly, especially in the fine particle size range. This is an area where further study could be directed in anticipation of particulate emission standards based on particle size as well as overall mass efficiency. Additional studies could be directed to deterioration in performance of control devices during extended operation, even with optimum maintenance.

5.3 FRACTIONAL EFFICIENCY RELATIONSHIPS

5.3.1 ESP's

As expected, computer modeling of the fractional efficiency of ESP's on kraft recovery furnaces and bark/fossil-fuel boilers showed a minimum in efficiency in the particle size range of 0.2 to 0.6 μm. This is due to the transition from field charging, which predominates for particles greater than 0.5 μm, to collection by diffusion, which predominates with particles below 0.5 μm. Absolute fractional efficiencies at the same overall mass efficiency depend very strongly on the inlet size distribution.

The predictions for bark boilers also account for the effects of re-entrainment, assuming that the fraction of material remains constant at different particle sizes and for each mechanical section. Minimum collection is still in the 0.2 to 0.4 μm range.

Fractional efficiency curves based on test data for kraft pulp mill recovery boilers are available[1,2] for comparison with predicted results. These test data confirm minimum collection efficiency in the 0.2 to 0.4 μm size range and show another minimum in the 8 to 10 μm range, which could be indicative of re-entrainment. Another test on an ESP with severe re-entrainment,[3] shows that collection efficiency continues to decline, leveling off at 70 to 100 μm. Re-entrainment in the larger size fractions supports the idea that the dust (most of which is re-entrained due to rapping) consists of both large particles and agglomerates of smaller particles.

Performance of ESP's on bark/fossil-fuel boilers with salt emissions was not modeled. The fractional efficiency, however, probably would be reduced because of the fine salt particles, with a resultant increase in opacity. No fractional efficiency test data were available for ESP's on bark/fossil-fuel boilers.

5.3.2 Venturi Scrubbers

The Research Cottrell computer model for predicting penetration as a function of particle size in venturi scrubbers on sludge lime kilns, crushers, and conveyors showed the characteristic deterioration in performance at particle sizes below about 2 micrometers. Cheremisinoff's particle data[4] on sludge lime kilns do not mention the presence of soda fume, which would add fine particles to the mix and could lead to pressure drops higher than those presented in the model for efficiencies above 99 percent.

No fractional efficiency test data for venturi scrubbers on the subject processes could be located for comparison with the predicted performance models.

5.3.3 Fabric Filters

A prediction model was not available for use in evaluating fractional efficiency performance of fabric filters. One set of fractional efficiency test data concerns EPA's mobile fabric filters applied to a kraft lime kiln.[5] This data supports the observation that fabric filters maintain collection efficiencies higher than ESP's or scrubbers in the submicron particle size range. No fractional efficiency test data are available for fabric filters applied to bark boilers or crushed stone processes.

Fabric filters operating on two bark boilers with a high percentage of submicron particles have yielded very low opacity readings, a further indication that the fabric filters are very efficient collectors of fine particles. Data from the utility industry also show that fabric filters can maintain an efficiency of 99 percent or greater in the submicrometer particle size range.

5.4 COSTS

Estimates of capital and annual operating costs for ESP's and wet scrubbers are based on data developed by Research Cottrell; estimates for fabric filters are derived from literature sources. Thus the cost estimates cannot be compared on the same basis. The intent was to estimate costs for the control device used predominantly on each of the subject processes. Some general conclusions follow.

In the past the almost exclusive use of ESP's on kraft recovery boilers was dictated primarily by the cost savings in the recovery of soda ash. This was balanced against the capital and operating costs over the life of the ESP, at efficiencies of 85 to 95 percent.[3,8] In recent years, however this savings has been reduced because requirements for higher precipitator efficiencies have led to higher operating costs not offset by the increase in market value of soda ash. Although retrofitting of venturi scrubbers downstream of an existing precipitator may provide a more economical option, such installations are infrequent and thus were not cost-evaluated.

The predominant use of venturi scrubbers on kraft lime kilns and of low-energy scrubbers on smelt dissolving tanks is dictated by the relatively higher capital cost of installing ESP's to handle small gas volumes. A recent comparison of ESP's and venturi scrubbers on a kraft lime kiln[6] noted that the capital investment for an ESP is 3 times greater and that the heat loss associated with the ESP is too great to overlook. The venturi scrubber was selected for the lime kiln.

For application to bark/fossil-fuel boilers, fabric filters are the most expensive control option, followed by ESP's and wet scrubbers. This observation is based on a recent report by Weyerhauser Corp.,[7] which estimates the costs of installing all three devices on a bark/fossil-fuel boiler with salt emissions.

Comparison of fabric filter and venturi scrubber applications on crushed stone processes shows that capital installed costs for venturi scrubbers are slightly higher and that operation and maintenance costs would be approximately 1-1/2 times those for fabric filters.

West dust suppresion can be used on primary crushers, screens, transfer points, and crusher feeds, where particle sizes are larger and moisture content is higher, in combination with fabric filters at points where fine particle emissions occur, primarily secondary and tertiary crushers and screens. This results in greater emission reduction than complete wet dust suppression, and is more economical than a complete fabric filter system.

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APPENDIX A-1

INSTALLATION LISTS FOR PARTICULATE CONTROL DEVICES ON KRAFT PULP MILL APPLICATIONS

Table A.1-1.

SELECTED
RESEARCH-COTTRELL, INC.
PULP MILL RECOVERY PRECIPITATORS

A. HORIZONTAL FLOW WET BOTTOM TYPE

Installation	No., Type & Size Recovery Units Lbs. BLS.[a]/Day & Pulp Equivalent	No. of Pptrs. Shell Material	Total Gas Flow (CFM) Gas Temp. (°F)
Tahsis Company, Ltd. Gold River, British Columbia, Canada	3,150,000 1050 T/Day	1 Hollow Tile	360,000 325
International Paper Co. Moss Point Mississippi	1,900,000 640 T/Day	1 Steel	211,000 300
Alabama Kraft Co. Phoenix City Alabama	2,750,000 915 T/Day	1 Filled Tile	305,000 300
Scott-Maritime Paper Co. Abercrombie Nova Scotia Canada	1,725,000 575 T/Day	1 Filled Tile	191,000 300
MacMillan & Bloedel Limited Powell River, Br. Columbia, Canada	2,250,000 750 T/Day	1 Filled Tile	285,000 325
Consolidated Pontiac, Inc. Portage Dufort Quebec, Canada	1,650,000 550 T/Day	1 Filled Tile	230,000 300
Owens-Illinois Corp. Orange Texas	(2) x 1,650,000 ea. (2) x 550 T/Day ea.	2 Filled Tile	360,000 300
Intercontinental Pulp Co., Ltd Prince George, B.C. Canda	2,550,000 850 T/Day	1 Steel	315,000 300

[a] BLS = Black Liquor Solids

(continued)

Table A.1-1 (continued).

Installation	No., Type & Size Recovery Units Lbs. BLS.[a]/Day & Pulp Equivalent	No. of Pptrs. Shell Material	Total Gas Flow (CFM) Gas Temp. (°F)
Tennessee River Pulp & Paper Co. Counce, Tenn.	1,250,000 415 T/Day	1 Filled Tile	173,000 325
Consolidated Papers Inc. Wisconsin Rapids Wisconsin	1,200,000 400 T/Day	1 Filled Tile	175,000 300
Eastex, Inc. Evadale, Texas	1,600,000 530 T/Day	1 Hollow Tile	190,000
Chesapeake Corp. of Virginia West Point, VA	2,400,000 bls/ day	2 Pilaster Filled Tile	245,000 325
Skookumchuk Pulp Cranbrook, B.C.	2,100,000 700 T/Day	1 Tile Shell	248,000 300
Potlach Forests Lewiston, Idaho	900,000 300 T/Day	1 Hollow Tile	104,500 325
Continental Can Co. Hopewell, Va.	1,050,000 350 T/Day	1 Steel (stainless)	175,000 250
Kimberly Clark Mexico	360,000 120 T/Day	1 Steel Pilaster	46,600 325
U.S. Plywood Champion Papers Courtland, Ala.		2 Tile Shell Pilaster	250,000/ pptr.
W. Va. Pulp & Paper Co. Wickliffe, Kentucky		1 Filled Tile Pilaster	270,000

[a] BLS = Black Liquor Solids

(continued)

Table A.1-1 (continued).

Installation	No., Type & Size Recovery Units Lbs. BLS.[a]/Day & Pulp Equivalent	No. of Pptrs Shell Material	Total Gas Flow (CFM) Gas Temp. (°F)
Boise Cascade De Ridder, La.		1 Filled Tile Pilaster	303,000
Southland Paper Mills, Inc. Lufkin, Texas		1 Filled Tile	140,000
St. Mary's Kraft Division Gilman Paper Co. St. Marys, Ga.		1 Filled Tile Pilaster	170,000 Total
Continental Can Co. Hopewell, VA.		1 Steel Heat Jacket	210,000 300
Hammermill Paper Co. Erie, Penna.		1 Steel Shell	325,000 acfm
International Paper Co. Texarkana, Texas		1 Steel Shell Opzel	250,000 325

[a] BLS = Black Liquor Solids

(continued)

Table A.1-1 (continued)

B. DRAG BOTTOM TYPE

Installation	No., Type	No. of Pptrs. Shell Material	Total Gas Flow (CFM) Gas Temp. (°F)
American Can Co. Halsey, Oregon	1 Kraft Recovery	1 Steel	164,240
International Paper Co., Inc. Glens Falls New York	1 Kraft Recovery	1 Steel	180,000
Weyerhaeuser Co. Springfield, Oregan Unit #4	1 Kraft Mill	1	249,000
Hoerner-Waldorf Corp. Missoula, Montana Boiler #3	1 Salt Cake	1 Opzel Filled Tile - Pilaster/ Plenums	207,000 400
Western Kraft Corp.	Salt Cake Collection (Controlled Odor)	1 Steel	230,000 365
Continental Can Hodge, Louisiana	1	1 Opzel Steel	390,000 340

Table A.1-2. INSTALLATION LIST FOR WET SCRUBBERS ON BARK BOILERS

Boiler steaming capacity lb/h	Type combustion chamber	Fuel major wood species	Type Scrubber	Scrubber ΔP, in. H_2O	Particulate emission, gr/dscf 12% CO_2	Mass emission rate, lb/h	Scrubber effluent discharge rate, gal/min.	Specific conductivity, 1000 umhos NEUT
60,000	SS	SP	Joy 28D Turbulaire	6	0.146[b]	12	5	
50,000	SS	DF,SP	Bumstead-Woolford	6	0.042	7	7	8-9
38,000	DO	DF	Joy 32DB Turbulaire	6	0.044	9.4	5	13
40,000	SS	SP	Zurn LP vertical venturi	6-8	0.055	8.2	1000 gal drained every 72 hours	14
120,000	SS	SP	Joy 56D	15	0.03	10.7	10	
30,000	DO	DF,SP	Bumstead-Woolford	6	0.046	7.6	100% recycle	11 (max.)
30,000	DO	DF,O, SP,C	Bumstead-Woolford	6	0.04		100% recycle	15 (max.)
60,000	SS	SP	Zurn LP vertical venturi	6-8			100% recycle lagoon	8.5[c]
110,000	SS	SP	Ducon	6			5	
105,000	TS		Western Precipitation variable vent.	8-10	0.022		Once through	
200,000	TS	DF,H	Western Precipitation variable vent.	15-20	0.0698		100% recycle	

[a] Data from 1) Mick, A.H. Wood Waste Fired Boilers: Wet Scrubber Technology, Georgia Pacific 69th Annual Meeting of the Air Pollution Control Association, Portland, Oregon 1976; and 2) Crown Zellerbach Corporation.

[b] Water level not maintained at manufacturers design specification.

[c] Operating 3 months - SC has not peaked, makeup water from city municipal treatment plant discharge.

Key

SP - Sugar Pine
C - Cedar
O - Oak
H - Hemlak
DO - Dutch Oven
DF - Douglas Fir
SP - Southern Pine
SS - Spreader Stoker
TS - Traveling grate stoker

Table A.1-3. INSTALLATION LIST FOR BARK/FOSSIL FUEL BOILERS[a]

Sic	Scc.	Address	B-cap. Mlb/hr	Type of control	Eff.
2611	10200901	LONGVIEW FIBER-POWER BOX637LONGVIEW98632	570.	MECHANICAL COLLECTOR	60.0
2611	10200902	BUCKEYE CELLULOSE CORP	225.	MECHANICAL COLLECTOR	90.0
2611	10200902	ITT RAYONIER, BX 191,PORT ANGELES 98368	0.	MECHANICAL COLLECTOR	83.0
2611	10200902	ITT RAYONIER, BX 191,PORT ANGELES 98368	299.	MECHANICAL COLLECTOR	50.0
2611	10200902	BRUNSWICK PULPAPAPER STHRN DOCKS 31520	592.	MECHANICAL COLLECTOR	80.0
2611	10200902	LOUISIANA-PAC.,PO BOX 158,SAMOA 95564	235.	MECHANICAL COLLECTOR	90.0
2611	10200902	LOUISIANA-PAC.,PO BOX 158,SAMOA 95564	340.	WET SCRUBBER	90.0
2611	10200902	OXFORD PPR-DIV ETHYL-RUMFORD 04276	274.	WET SCRUBBER	96.0
2611	10200902	WEYERHAEUSER-POWER , LONGVIEW 98632	690.	MECHANICAL COLLECTOR	90.0
2611	10200902	NEKOOSA EDWARDS PAPER,BX96,ASHDOWN410002	275.	MECHANICAL COLLECTOR	95.0
2611	10200902	SCOTT PAPER 2600 FEDERAL AVE EVRTT 98201	60.	MISCELLANEOUS	40.0
2611	10200902	WEYCO,COSMOPOLIS 98537	182.	MECHANICAL COLLECTOR	50.0
2611	10200902	ALASKA LUMBER & PULP BX 1050 SITKA 99835	165.	MECHANICAL COLLECTOR	85.0
2611	10200902	ALASKA LUMBER & PULP BX 1050 SITKA 99835	165.	MECHANICAL COLLECTOR	85.0
2611	10200902	SCOTT PPR CO-NORTHEAST OP-WINSLOW 04902	160.	MISCELLANEOUS	85.0
2611	10200902	ST REGIS KRAFT,801 CANAL, TACOMA, 98421	85.	MECHANICAL COLLECTOR	.0
2611	10200902	ST REGIS KRAFT,801 CANAL, TACOMA, 98421	85.	MECHANICAL COLLECTOR	.0
2611	10200902	ST REGIS KRAFT,801 CANAL, TACOMA, 98421	60.	MECHANICAL COLLECTOR	.0
2611	10200902	ST REGIS KRAFT,801 CANAL, TACOMA, 98421	90.	MECHANICAL COLLECTOR	.0
2611	10200902	ITT RAYONIER BX207 JESUP 31545	144.	MECHANICAL COLLECTOR	90.0
2611	10200902	ITT RAYONIER BX207 JESUP 31545	180.	MECHANICAL COLLECTOR	92.0
2611	10200902	KETCHIKAN PULPCO BOX 1619 KTN 99901	336.	MECHANICAL COLLECTOR	90.0
2611	10200902	ITT RAYONIER,INC BOX249 HOQUIAM 98550	0.	WET SCRUBBER	93.0
2611	10200902	ITT RAYONIER,INC BOX249 HOQUIAM 98550	187.	MECHANICAL COLLECTOR	55.0
2611	10200902	WEYERHAEUSER -CO BOX 1228 EVERETT 98201	80.	MECHANICAL COLLECTOR	90.0
2611	10200902	WEYERHAEUSER -CO BOX 1228 EVERETT 98201	80.	MECHANICAL COLLECTOR	90.0
2611	10200902	WEYERHAEUSER -CO BOX 1228 EVERETT 98201	80.	MECHANICAL COLLECTOR	90.0
2611	10200903	MANISTIQUE PULP AND PAPER CO MANISTIQUE	90.	MECHANICAL COLLECTOR	85.0
2611	10200901	CROWN ZELLERBACH,BOGALUSA	317.	MECHANICAL COLLECTOR	75.0
2621	10200901	MEAD CORPORATION 45601	422.	MECHANICAL COLLECTOR	84.0
2621	10200901	BOISE CASCADE CORP	300.	MECHANICAL COLLECTOR	75.0
2621	10200901	BOISE CASCADE CORP	300.	MECHANICAL COLLECTOR	75.0
2621	10200901	INT.PAPER CO.LOWER WOODVILLE RD,NATCHEZ	70.	MECHANICAL COLLECTOR	85.0
2621	10200901	INT.PAPER CO.LOWER WOODVILLE RD,NATCHEZ	210.	MECHANICAL COLLECTOR	85.0
2621	10200901	INT.PAPER CO.LOWER WOODVILLE RD,NATCHEZ	210.	MECHANICAL COLLECTOR	85.0
2621	10200901	CHAMPION PAPERS PASADENA TEXAS 77501	0.	WET SCRUBBER	75.0
2621	10200901	CHAMPION PAPERS PASADENA TEXAS 77501	0.	WET SCRUBBER	75.0
2621	10200901	CHAMPION PAPERS PASADENA TEXAS 77501	0.	WET SCRUBBER	75.0
2621	10200901	US PLYWOOD-CHAMPION PAPER COURTLAND RD29	398.	MISCELLANEOUS	88.0
2621	10200901	US PLYWOOD-CHAMPION PAPER COURTLAND RD29	479.	ELECTRO STATIC PRECIPITATION	99.0
2621	10200901	SOUTHLND PPR MILLS LUFKIN MILL HWY 103	166.	MECHANICAL COLLECTOR	99.0
2621	10200901	KIMBERLY-CLARK CORP. COOSA PINES	115.	MISCELLANEOUS	70.0
2621	10200901	KIMBERLY-CLARK CORP. COOSA PINES	123.	MISCELLANEOUS	70.0
2621	10200901	KIMBERLY-CLARK CORP. COOSA PINES	318.	MISCELLANEOUS	91.0
2621	10200901	ST REGIS PAPER CO 659 EASTPORT RD JAX FL	193.	MECHANICAL COLLECTOR	90.0
2621	10200901	ST REGIS PAPER CO 659 EASTPORT RD JAX FL	193.	MECHANICAL COLLECTOR	90.0
2621	10200901	CONTAINER CORP OF AM P O BOX 709 BREWTON	279.	MECHANICAL COLLECTOR	92.0
2621	10200901	CONTAINER CORP OF AM P O BOX 709 BREWTON	351.	MECHANICAL COLLECTOR	92.0
2621	10200901	INTL PPR-ANDROSCOGGIN MILL-JAY 04254	300.	MISCELLANEOUS	96.0
2621	10200901	INTERNATIONAL PAPER CO TEXARKANA TEXAS	781.	MECHANICAL COLLECTOR	93.0
2621	10200901	BOWATERS PAPER CO CALHOUN 37309	238.	MISCELLANEOUS	75.0
2621	10200901	TENN R PULP PAPER CO BX 33 COUNCE 38326	280.	MECHANICAL COLLECTOR	92.0
2621	10200901	EASTEX INC EVADALE TX	344.	MECHANICAL COLLECTOR	85.0
2621	10200901	EASTEX INC EVADALE TX	344.	MECHANICAL COLLECTOR	85.0

Table A.1-3 (continued)

Sic	Scc.	Address	B-cap. Mlb/hr	Type of control	Eff.
2021	10200901	ALLIED PAPER INC 36505	74.	MECHANICAL COLLECTOR	90.0
2021	10200902	ST JOE PAPER CO US 98 PORT ST JOE	300.	MECHANICAL COLLECTOR	80.0
2021	10200902	HOERNER-WALDORF ROANOKE RAPIDS	500.	WET SCRUBBER	98.0
2021	10200902	FEDERAL PAPERBOARD RIEGELWOOD NC 28456	100.	MECHANICAL COLLECTOR	92.0
2021	10200902	FEDERAL PAPERBOARD RIEGELWOOD NC 28456	384.	MECHANICAL COLLECTOR	95.0
2021	10200902	UNION CAMP CORP BOX 326 MONTGOMERY 36101	640.	MECHANICAL COLLECTOR	90.0
2021	10200902	ST REGIS PAPER MONTICELLO 39654	814.	MECHANICAL COLLECTOR	90.0
2021	10200902	ALTON BOX BOARD CO 1915 WIGMORE JAX32206	330.	MECHANICAL COLLECTOR	90.0
2021	10200902	MOSINEE PAPER CORP 54455	106.	MECHANICAL COLLECTOR	70.0
2021	10200902	UNION CAMP CORP PAPER BOD DIV FRANKLIN	490.	MECHANICAL COLLECTOR	80.0
2021	10200902	UNION CAMP CORP PAPER BOD DIV FRANKLIN	520.	MECHANICAL COLLECTOR	80.0
2021	10200902	ALABAMA KRAFT CO BOX 940 36867	337.	MECHANICAL COLLECTOR	90.0
2021	10200902	S CAR INDUSTRIES BOX8000 FLORENCE 29501	342.	MECHANICAL COLLECTOR	75.0
2021	10200902	BIRON DIV CONSOLIDATED PAPERS 54494	60.	MECHANICAL COLLECTOR	90.0
2021	10200902	CONSOLIDATED PAPERS 4TH AVE N 54494	250.	MECHANICAL COLLECTOR	80.0
2021	10200902	CONSOLIDATED PAPERS 4TH AVE N 54494	250.	MECHANICAL COLLECTOR	80.0
2021	10200902	ST REGIS PAPER CO	97.	MECHANICAL COLLECTOR	99.0
2021	10200902	GEORGIA-PACIFIC CRP BOX 1236 BLNGH 98225	60.	MECHANICAL COLLECTOR	85.0
2021	10200902	AMERICAN CAN CO HWY 51 ROTHSCHILD 54474	55.	MECHANICAL COLLECTOR	75.0
2021	10200902	AMERICAN CAN CO HWY 51 ROTHSCHILD 54474	99.	MECHANICAL COLLECTOR	78.0
2021	10200902	GULF STATES PAPER CORP RIVER RD 35401	50.	MECHANICAL COLLECTOR	92.0
2021	10200902	GULF STATES PAPER CORP RIVER RD 35401	50.	MECHANICAL COLLECTOR	92.0
2021	10200902	GULF STATES PAPER CORP 36732	282.	MISCELLANEOUS	80.0
2021	10200902	CONTAINER CORP OF AMER N 8TH ST FERN.BCH	325.	MECHANICAL COLLECTOR	92.0
2021	10200902	CONTAINER CORP OF AMER N 8TH ST FERN.BCH	650.	MECHANICAL COLLECTOR	92.0
2021	10200902	ARKANSAS KRAFT CO. MORRILTON ,150001	75.	MECHANICAL COLLECTOR	90.0
2021	10200902	PUBLISHERS PAPER CORPO BOX 70 NEWBERG	0.	WET SCRUBBER	98.0
2021	10200902	SCOTT PAPER COMPANY BAY BRIDGE RD MOBILE	500.	MECHANICAL COLLECTOR	80.0
2021	10200902	CROWN SIMPSON PULP MILL,FAIRHAVEN 95501	195.	MECHANICAL COLLECTOR	88.0
2021	10200902	SCOTT PAPER CO CENTRAL AV OCNT FLLS54154	85.	MECHANICAL COLLECTOR	80.0
2021	10200902	POTLATCH CORP BOX1016 LEWISTON 83501	91.	MECHANICAL COLLECTOR	90.0
2021	10200902	BOWATERS CAROLINA CORP BOX7 CATAWBA29704	392.	MISCELLANEOUS	90.0
2021	10200902	BOWATERS CAROLINA CORP BOX7 CATAWBA29704	490.	MISCELLANEOUS	95.0
2021	10200902	INTERNATIONAL PAPER SIEBERT STATION	215.	MECHANICAL COLLECTOR	50.0
2021	10200902	INTERNATIONAL PAPER SIEBERT STATION	770.	MECHANICAL COLLECTOR	99.0
2021	10200902	INTERNATIONAL PAPER GEORGETOWN 29440	180.	MECHANICAL COLLECTOR	85.0
2021	10200902	INTERNATIONAL PAPER GEORGETOWN 29440	200.	MECHANICAL COLLECTOR	85.0
2021	10200902	INT PAPER,2019 GRIERSON,MOSS PT,39563	355.	MECHANICAL COLLECTOR	80.0
2021	10200902	ST REGIS PAPER CO 659 EASTPORT RD JAX FL	195.	MECHANICAL COLLECTOR	90.0
2021	10200902	ST REGIS PAPER CO 659 EASTPORT RD JAX FL	195.	MECHANICAL COLLECTOR	90.0
2021	10200902	HUDSON PULP & PAPER 3M216 PALATKA 32077	200.	MECHANICAL COLLECTOR	90.0
2021	10200902	GEORGIA PACIFIC,B.520,CROSSETT 020013	186.	WET SCRUBBER	90.0
2021	10200902	GEORGIA PACIFIC,B.520,CROSSETT 020013	202.	WET SCRUBBER	90.0
2021	10200902	GEORGIA PACIFIC,B.520,CROSSETT 020013	209.	WET SCRUBBER	90.0
2021	10200902	CROWN ZELLERBACH CO N. SANTIAM HWY LEBAN	0.	MECHANICAL COLLECTOR	98.0
2021	10200902	CROWN ZELLERBACH CO N. SANTIAM HWY LEBAN	0.	MECHANICAL COLLECTOR	80.0
2021	10200902	CROWN ZELLERBACH CO N. SANTIAM HWY LEBAN	0.	MECHANICAL COLLECTOR	88.0
2021	10200902	OWENS-ILL FOREST PROD DIV TOMAHAWK 54487	30.	ELECTRO STATIC PRECIPITATOR	95.0
2021	10200902	OWENS-ILL FOREST PROD DIV TOMAHAWK 54487	105.	ELECTRO STATIC PRECIPITATOR	85.0
2021	10200902	GA-PACIFIC CORP,MILL ST,WOODLAND 04694	813.	MECHANICAL COLLECTOR	75.0
2021	10200902	HOERNER-WALDORF DIV., CHAMPION INTERNATI	228.	MISCELLANEOUS	98.0
2021	10200902	WARREN,S D-DIV SCOTT PPR-CUMBERLAND ST	130.	ELECTRO STATIC PRECIPITATOR	75.0
2021	10200902	CROWN ZELLERBACH WEST LINN	0.	WET SCRUBBER	98.0
2021	10200902	CROWN ZELLERBACH WEST LINN	0.	WET SCRUBBER	98.0
2021	10200902	WESTVACO CORP BLEACHED BOARD DIV COV	708.	ELECTRO STATIC PRECIPITATOR	99.0
2021	10200902	WESCOR BOX R HWY 1406 HAWESVILLE 42348	0.	WET SCRUBBER	77.0
2021	10200902	GRT NORTH-NEKOOSA PPR-MILLINOCKET 04462	370.	MISCELLANEOUS	85.0
2021	10200902	WEYERHAEUSER CO P O BOX 1391 28560	388.	MECHANICAL COLLECTOR	92.0
2021	10200902	BOISE CASCADE CO BOX W STEILACOOM 98388	80.	MISCELLANEOUS	50.0
2021	10200902	BOISE CASCADE CO BOX W STEILACOOM 98388	82.	MISCELLANEOUS	50.0

Table A.1-3 (continued)

Sic	Scc.	Address	B-cap. Mlb/hr	Type of control	Eff.
2621	10200902	WEYERHAEUSER CO BX 1065 PLYMOUTH 96801	167.	MECHANICAL COLLECTOR	83.0
2621	10200902	WEYERHAEUSER CO BX 1065 PLYMOUTH 96801	354.	MECHANICAL COLLECTOR	90.0
2621	10200902	PUBLISHERS PAPER CO 419 MAIN ST OREGON C	0.	MECHANICAL COLLECTOR	94.0
2621	10200902	INTERNATIONAL PAPER CO PANAMA CITY FLA	378.	WET SCRUBBER	90.0
2621	10200902	INTERNATIONAL PAPER CO PANAMA CITY FLA	397.	WET SCRUBBER	90.0
2621	10200902	CROWN ZELLERBACH&PONDERS CAMAS 98607	59.	MECHANICAL COLLECTOR	45.0
2621	10200902	CROWN ZELLERBACH&PONDERS CAMAS 98607	120.	MECHANICAL COLLECTOR	30.0
2621	10200902	CROWN ZELLERBACH&PONDERS CAMAS 98607	120.	MECHANICAL COLLECTOR	30.0
2621	10200902	BOWATERS PAPER CO CALHOUN 37309	111.	MISCELLANEOUS	75.0
2621	10200902	NEKOOSA EDWARDS 100 WISC RIVER DR 54469	253.	MECHANICAL COLLECTOR	77.0
2621	10200902	WESTVACO KRAFT DIV N CHARLESTON 29406	192.	MECHANICAL COLLECTOR	87.0
2621	10200902	WESTVACO KRAFT DIV N CHARLESTON 29406	310.	MECHANICAL COLLECTOR	80.0
2621	10200902	ITT RAYONIER FERNANDINA BEACH 32034	190.	MISCELLANEOUS	90.0
2621	10200902	ITT RAYONIER FERNANDINA BEACH 32034	240.	MISCELLANEOUS	90.0
2621	10200902	INTNL.PAPER CO.B.7009,PINE BLUFF 350018	171.	MECHANICAL COLLECTOR	95.0
2621	10200902	THILMANY PULP&PAPER CO KAUKAUNA 54130	98.	MECHANICAL COLLECTOR	40.0
2621	10200902	FIBERBOARD CORP WILBUR AVE ANTIOCH	0.	MISCELLANEOUS	.0
2621	10200902	FLAMBEAU PAPER CO,200 FIRST AVE N, 54552	51.	MECHANICAL COLLECTOR	85.0
2621	10200902	FLAMBEAU PAPER CO,200 FIRST AVE N, 54552	83.	MECHANICAL COLLECTOR	85.0
2621	10200902	AMERICAN CAN CO PENNINGTON 36904	0.	MECHANICAL COLLECTOR	93.0
2621	10200902	AMERICAN CAN CO PENNINGTON 36904	425.	MECHANICAL COLLECTOR	70.0
2621	10200903	KIMBERLY CLARK MUNISING MILL 601 E MUNIS	180.	MECHANICAL COLLECTOR	85.0
2621	10200903	WESTON PAPER & MFG FRANKLTON & VOORHEES	100.	MISCELLANEOUS	85.0
2621	10200903	WESTON PAPER & MFG FRANKLTON & VOORHEES	210.	MISCELLANEOUS	85.0
2621	10200903	PH GLATFELTER-SPR GROVE-228 MAIN ST	277.	WET SCRUBBER	90.0
2621	10200903	MEAD PAPER COMPANY 49029	260.	MECHANICAL COLLECTOR	90.0
2621	10200903	SCOTT PAPER CO-SOMERSET PLANT FAIRFIELD	627.	MECHANICAL COLLECTOR	92.0
2621	10200903	PACKAGING CORP OF AMERICA 2285 ODELL ST	60.	MECHANICAL COLLECTOR	85.0
2621	10200903	INTERNATIONAL P TICONDEROGA MIL TICONDER	640.	MECHANICAL COLLECTOR	95.0
2631	10200901	CONTINENTAL CAN CO BOX 4068	97.	MECHANICAL COLLECTOR	92.0
2631	10200901	INT.PAPER CO.MBT.SN,REDWOOD	870.	MECHANICAL COLLECTOR	98.0
2631	10200901	WILLAMETTE IND WESTERN KRAFT DIV CAMPTI	421.	WET SCRUBBER	90.0
2631	10200901	GREAT SOUTHERN PAPER CO	780.	WET SCRUBBER	95.0
2631	10200902	GEORGIA PACIFIC CORPPO BOX 580 TOLEDO	0.	MECHANICAL COLLECTOR	94.0
2631	10200902	GEORGIA PACIFIC CORPPO BOX 580 TOLEDO	0.	MECHANICAL COLLECTOR	94.0
2631	10200902	INT'L PAPER CO LA.MILL BASTROP LA 71220	0.	ELECTRO STATIC PRECIPITATOR	98.0
2631	10200902	CONTINENTAL CAN PORT1408 AUGUSTA 30903	480.	MECHANICAL COLLECTOR	30.0
2631	10200902	CONTINENTAL CAN CO PORT 201 HOPEWELL860	277.	MECHANICAL COLLECTOR	88.0
2631	10200902	WESTERN KRAFT CORP 1-5 AT NORTH ALBANY	0.	MECHANICAL COLLECTOR	94.0
2631	10200902	CHESAPEAKE CORPORATION OF VA WEST POINT	111.	MECHANICAL COLLECTOR	96.0
2631	10200902	MENASHA CORPORATION JORDAN POINT, NORTH	0.	MECHANICAL COLLECTOR	94.0
2631	10200902	MENASHA CORPORATION JORDAN POINT, NORTH	0.	MECHANICAL COLLECTOR	94.0
2631	10200903	INLAND CONTAINER BX 299 NEW JOHNV 37134	527.	MISCELLANEOUS	98.0
2631	10200903	HOERNER WALDORF CORP 115 LAKESHORE ROAD	375.	MECHANICAL COLLECTOR	83.0
2631	10201301	INLAND CONTAINER BX 299 NEW JOHNV 37134	527.	MISCELLANEOUS	98.0
2645	10200902	HAMMERMILL PAPER CO-1563 E LAKE RD-ERIE	298.	MECHANICAL COLLECTOR	92.0
2653	10200902	INTERNATIONAL PAPER, WEED	120.	MECHANICAL COLLECTOR	.0
2653	10200902	INTERNATIONAL PAPER, WEED	120.	MECHANICAL COLLECTOR	.0
2653	10200902	INTERNATIONAL PAPER, WEED	120.	MECHANICAL COLLECTOR	.0
2653	10200902	INTERNATIONAL PAPER, WEED	120.	MECHANICAL COLLECTOR	.0
2653	10200902	INTERNATIONAL PAPER, WEED	120.	MECHANICAL COLLECTOR	.0
2655	10200902	SONOCO PRODUCTS CO HARTSVILLE S C 29550	284.	MECHANICAL COLLECTOR	80.0
2661	10200902	ABITIBI CORP ROARING RIVER	87.	MISCELLANEOUS	40.0
2661	10200902	UNION CAMP BLDG PROD DIV BOX 178 FRANKLN	100.	MECHANICAL COLLECTOR	92.0

APPENDIX A-2

CAPITAL AND ANNUAL COSTS OF PRECIPITATORS FOR PULP MILL APPLICATIONS

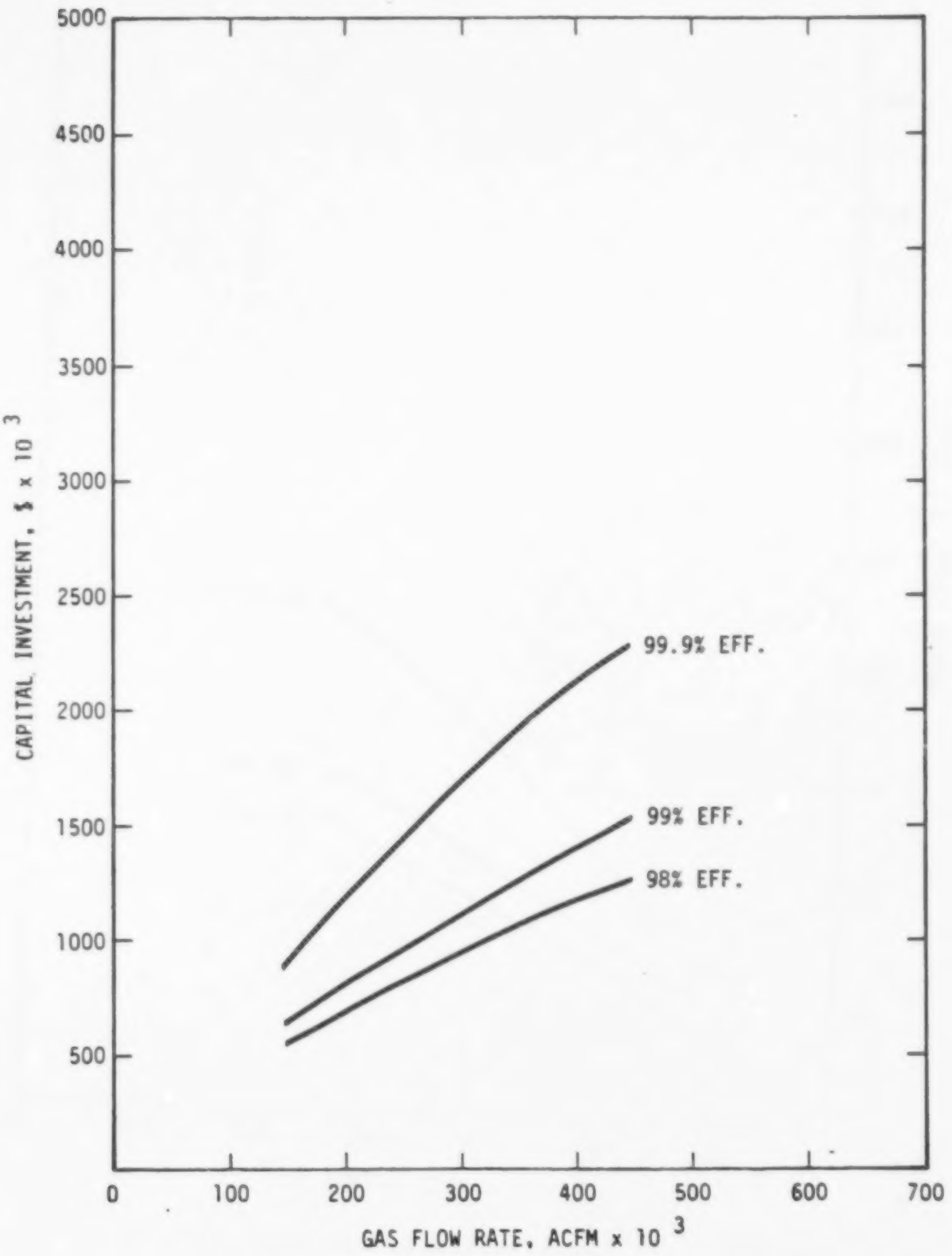

Figure A.2-1. Capital investment for precipitators on conventional (high-odor) recovery furnaces.

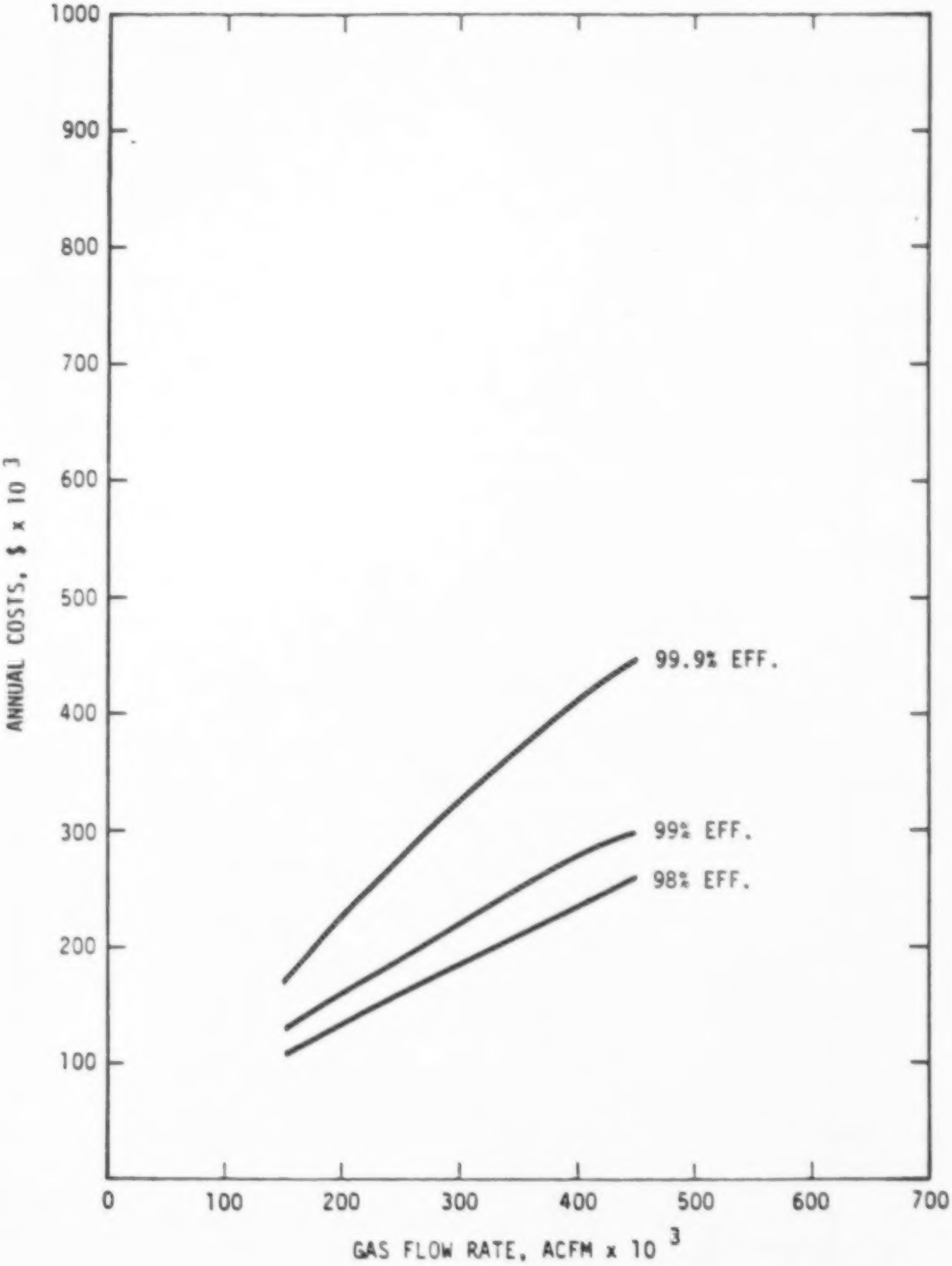

Figure A.2-2. Annual costs for precipitators on conventional (high-odor) recovery furnaces.

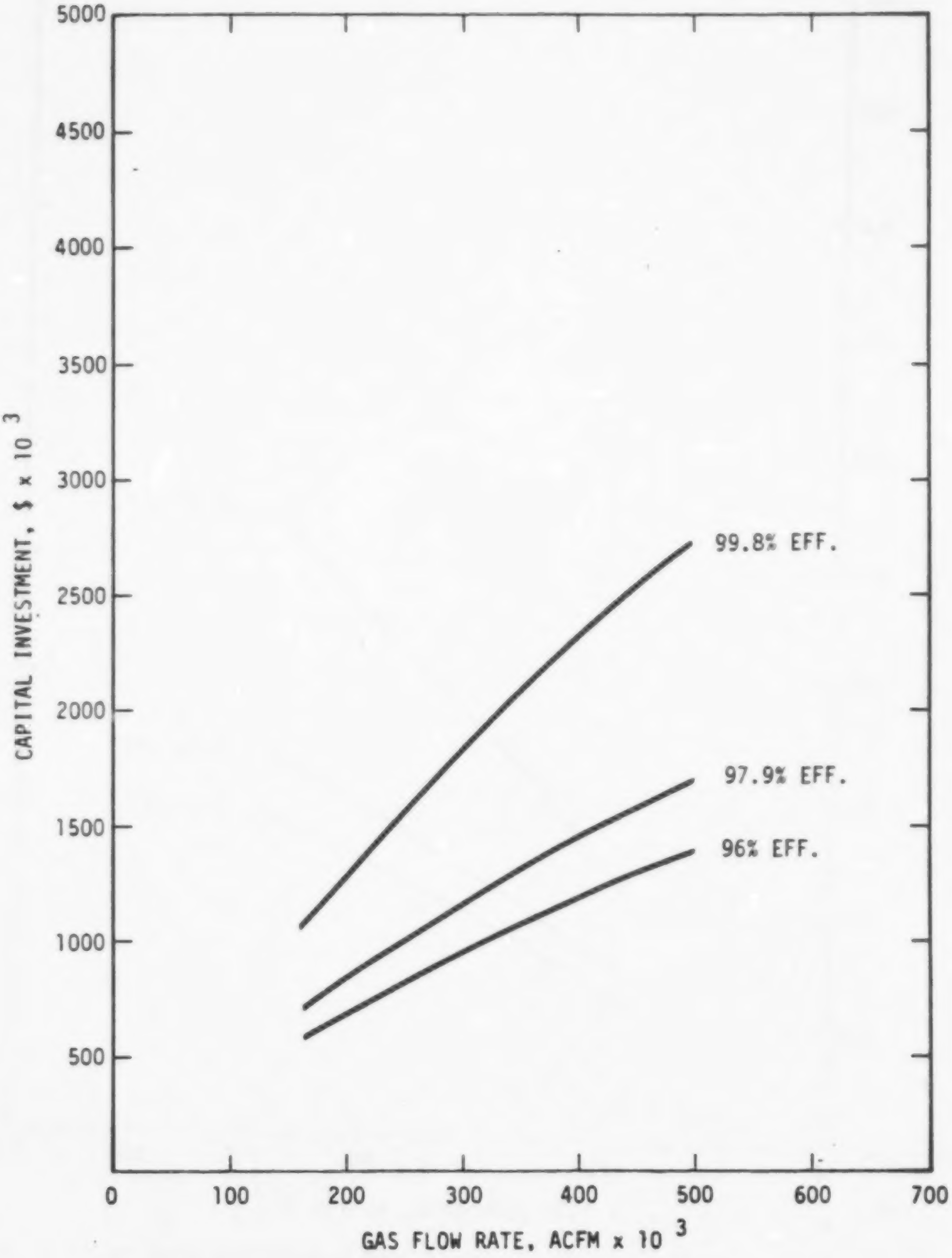

Figure A.2-3. Capital investment for precipitators on low-odor recovery furnaces.

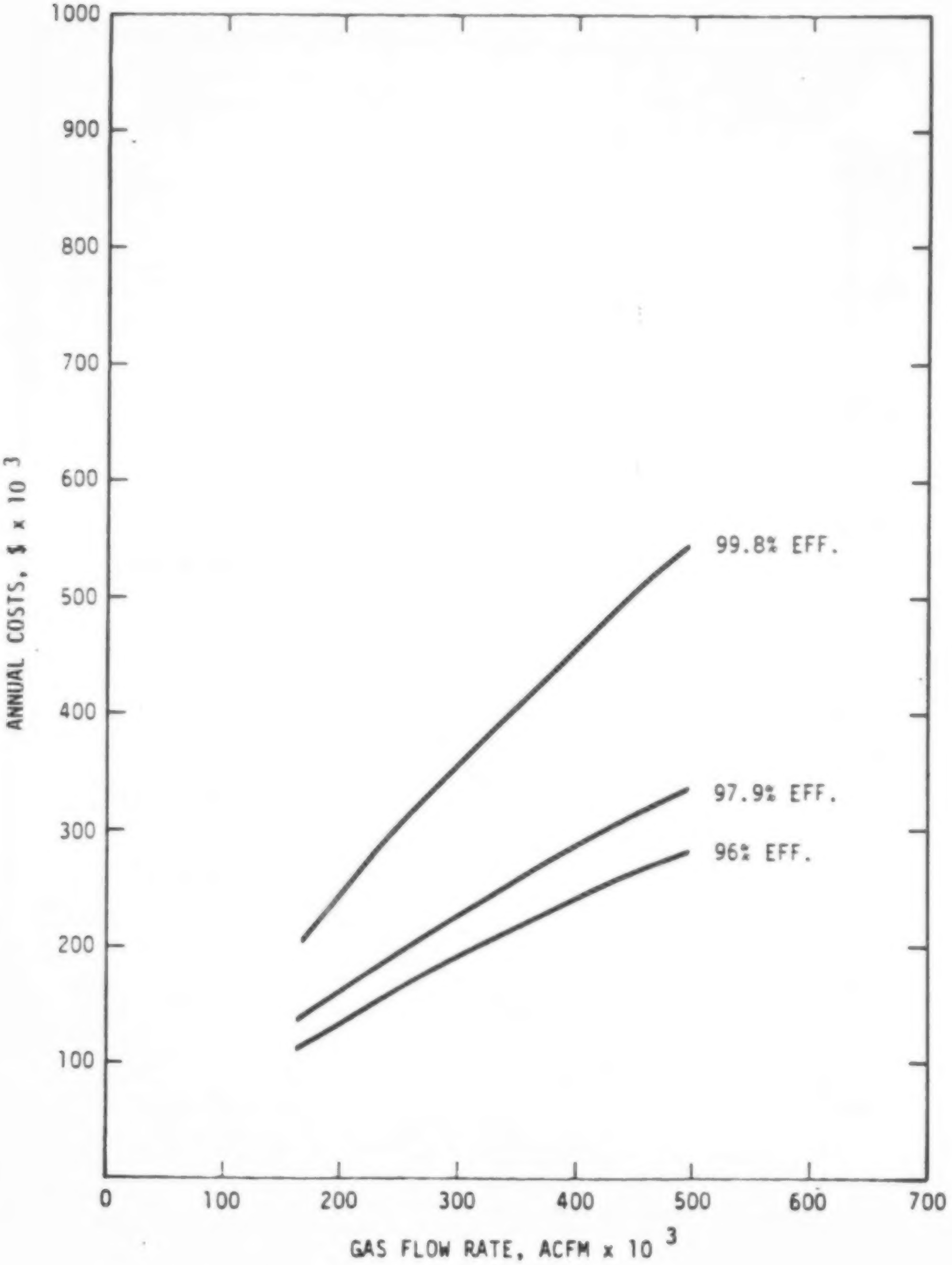

Figure A.2-4. Annual costs for precipitators on low-odor recovery furnaces.

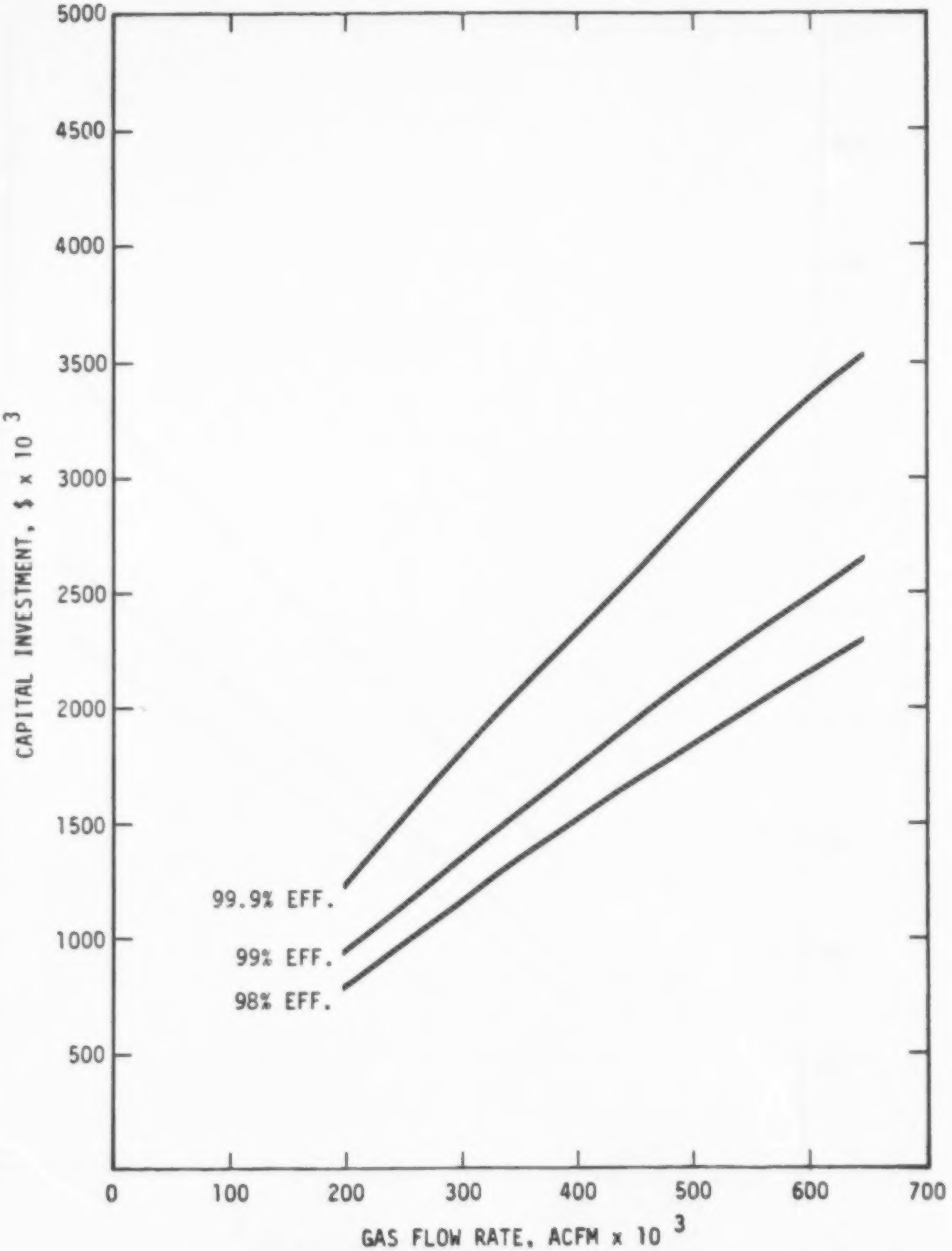

Figure A.2-5. Capital investment for precipitators on bark combination bark fossil fuel-fired boilers.

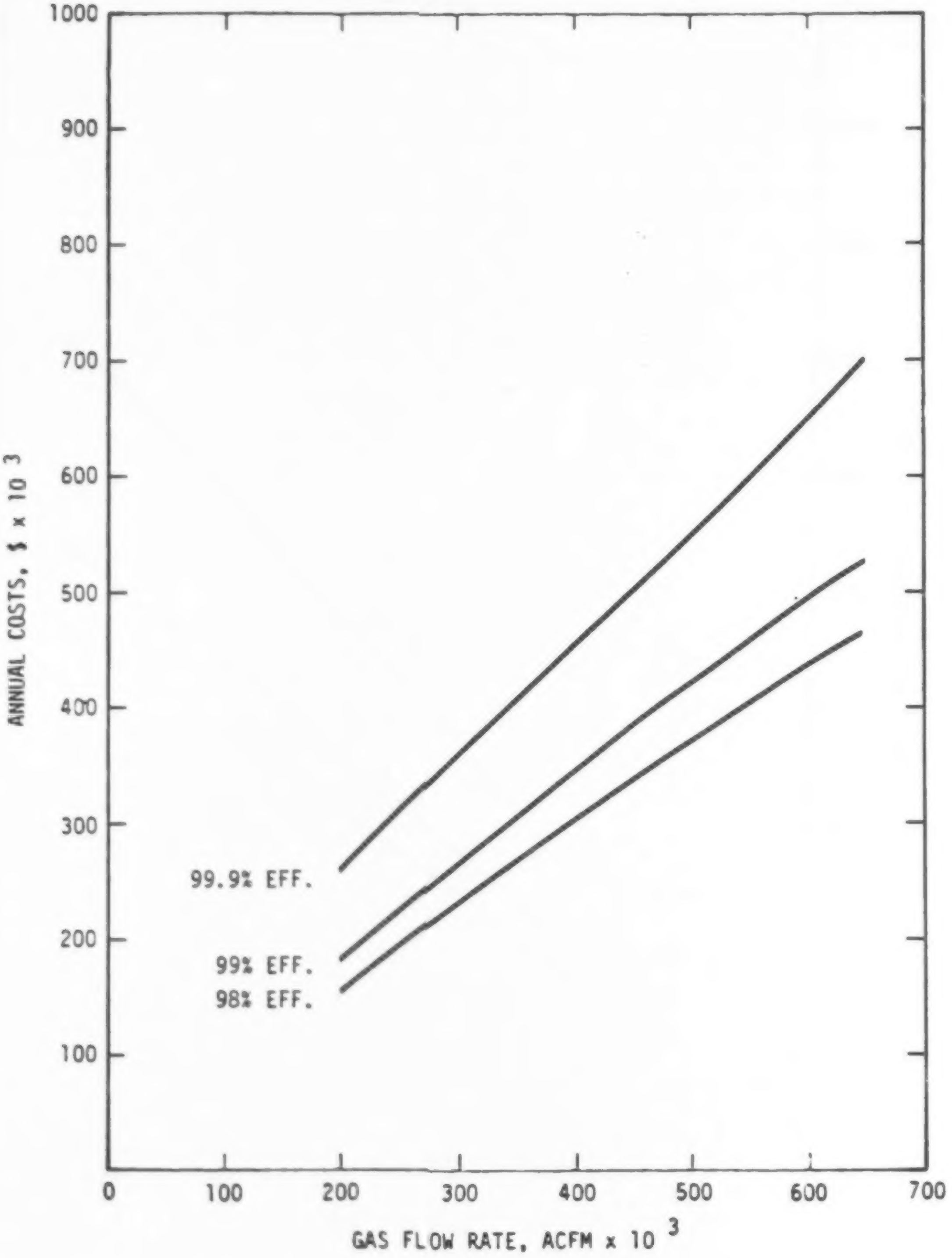

Figure A.2-6. Annual costs for precipitators on bark combination bark fossil fuel-fired boilers.

APPENDIX A-3

CAPITAL AND ANNUAL COSTS OF VENTURI SCRUBBERS ON KRAFT PULP MILL AND CRUSHED STONE INDUSTRY PROCESSES

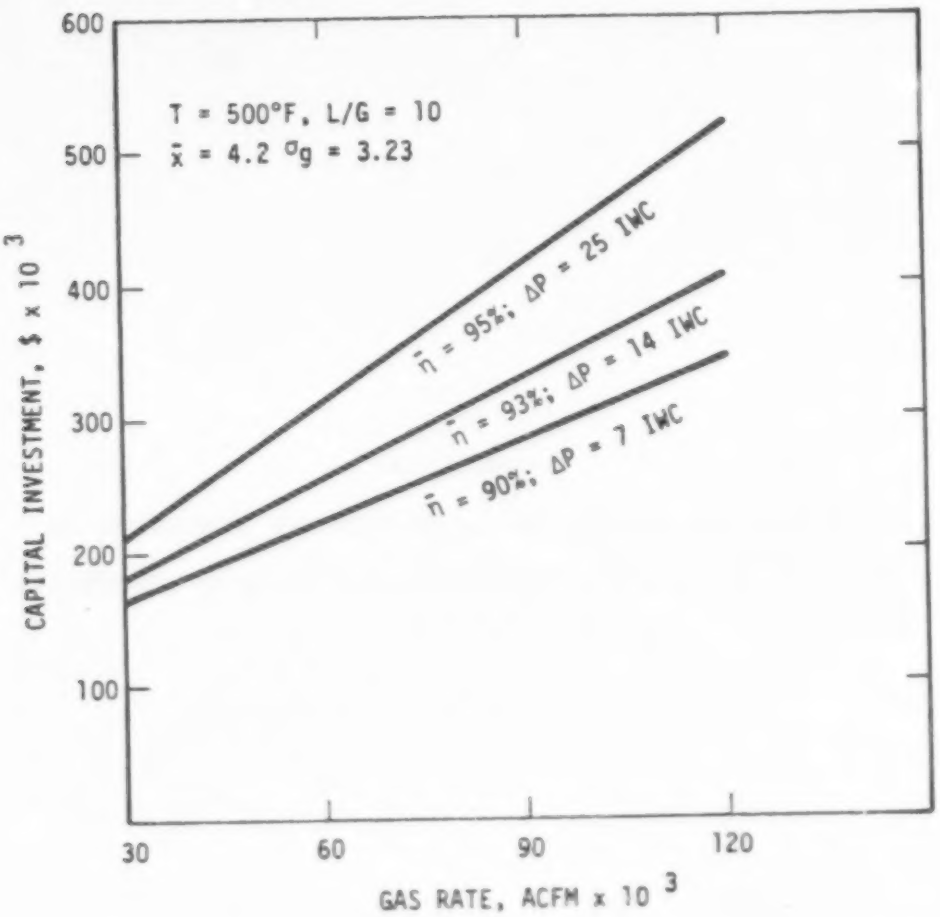

Figure A.3-1. Effects of collection efficiency and gas rate on the capital investment of venturi scrubber systems for lime kilns.

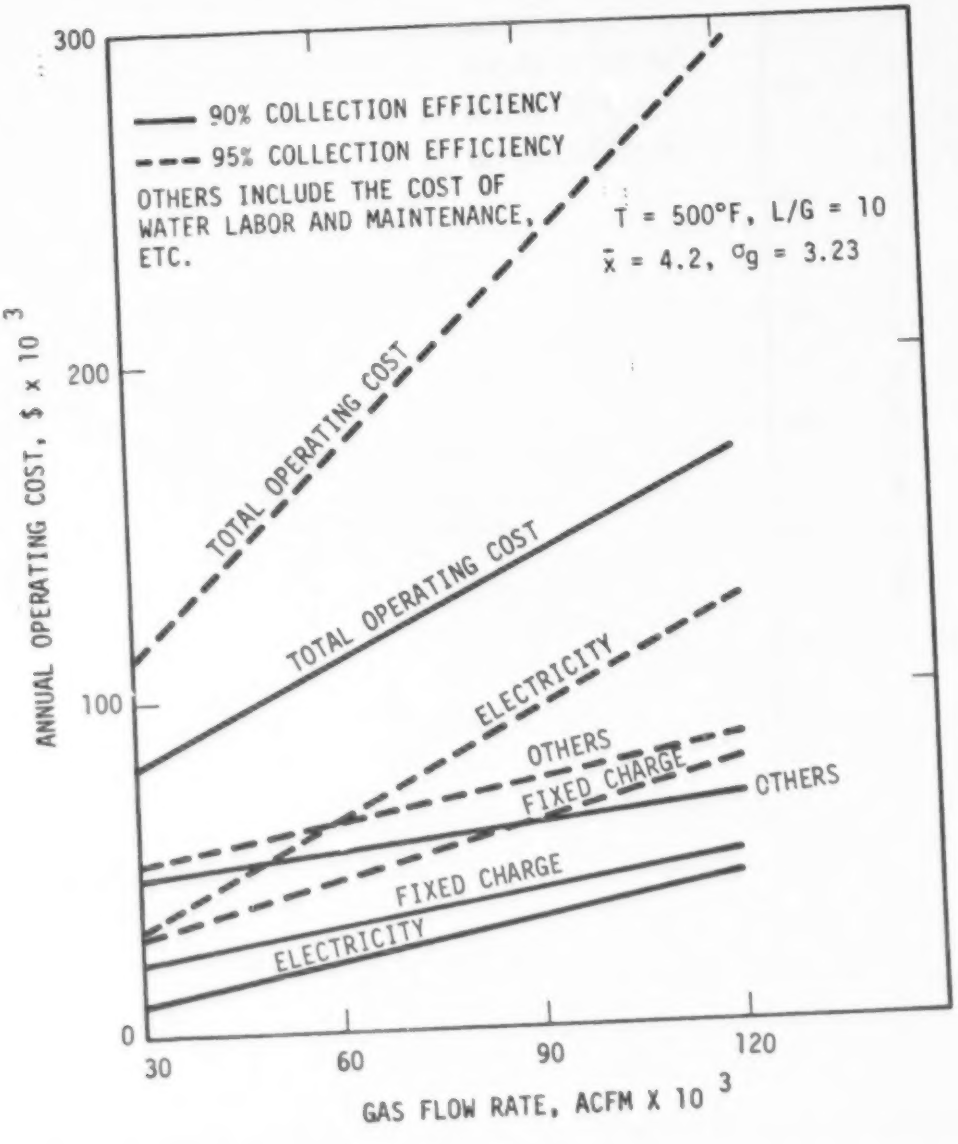

Figure A.3-2. Effects of gas rate, electricity usage, fixed charges, and others on the annual costs of venturi scrubber systems for lime kilns.

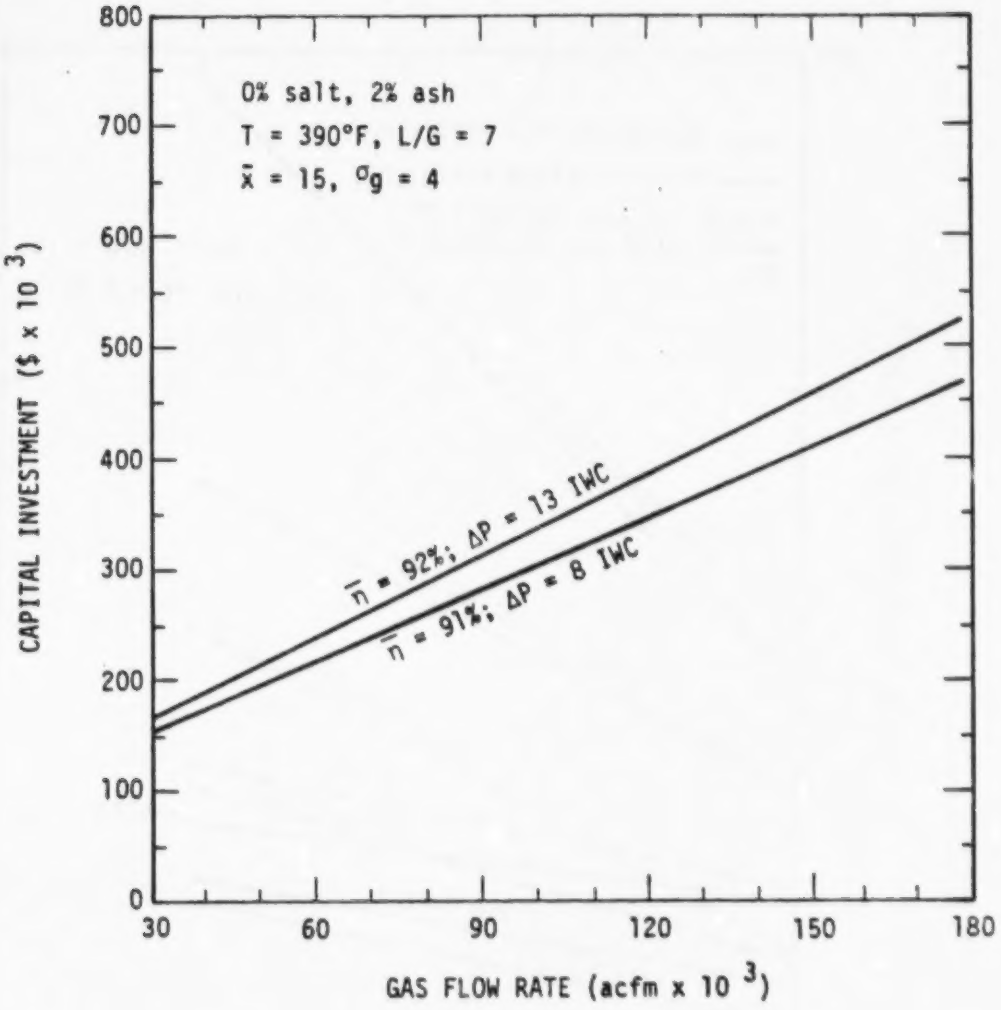

Figure A.3-3. Effects of collection efficiency and gas rate on the capital investment of venturi scrubber systems for bark/fossil fuel boilers.

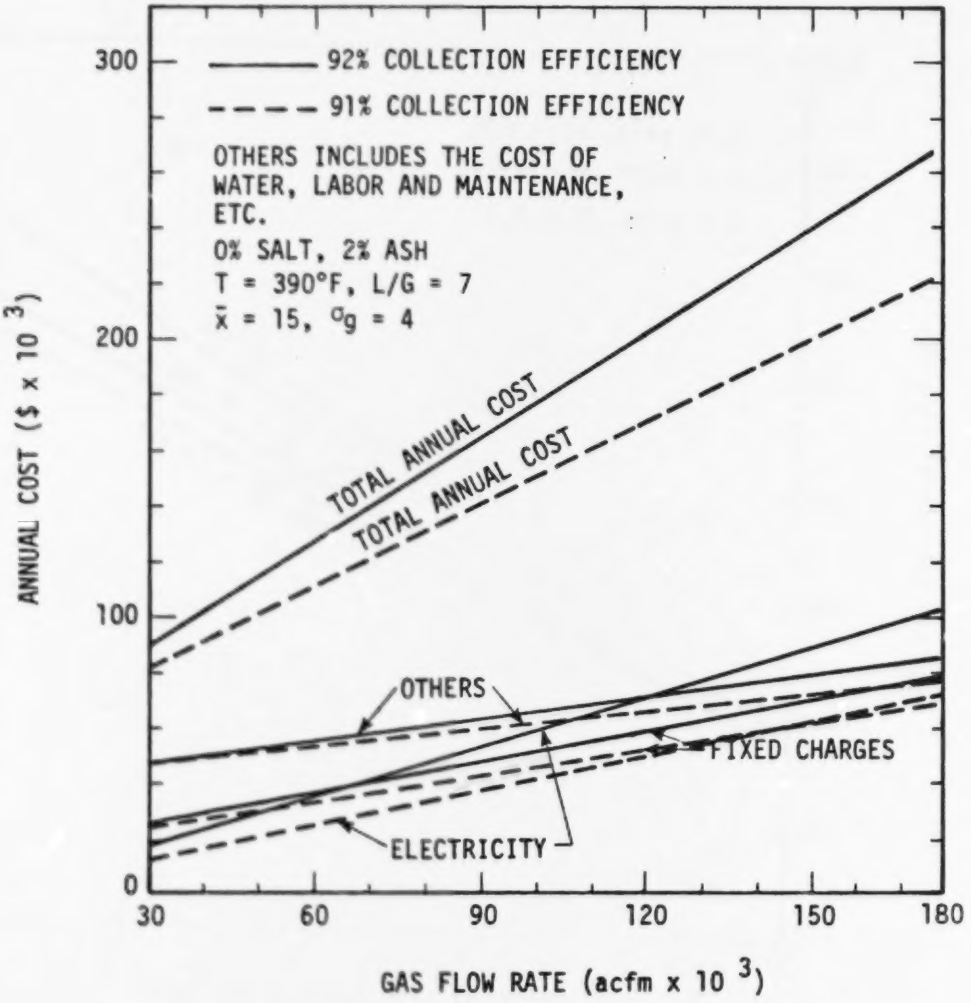

Figure A.3-4. Effects of gas rate, electricity usage, fixed charges and others on the annual costs of venturi scrubber systems for bark/fossil fuel fired boilers.

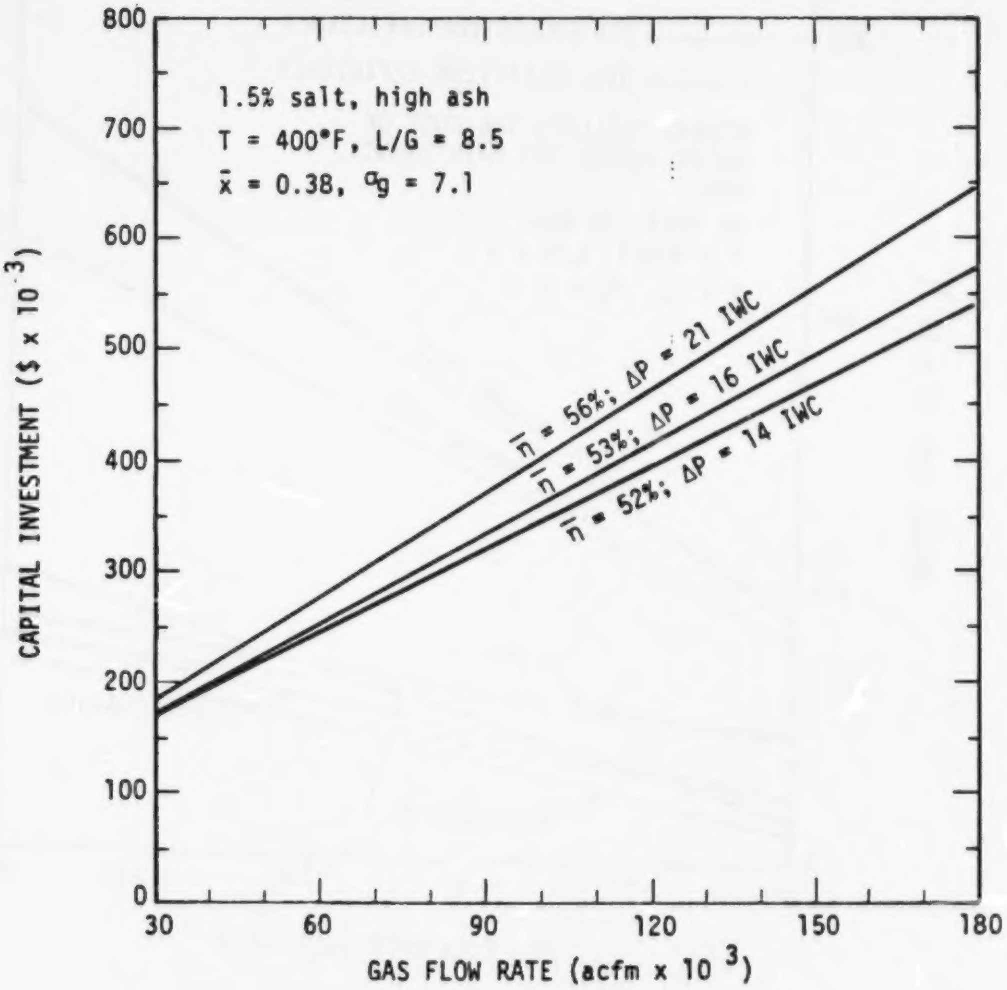

Figure A.3-5. Effects of collection efficiency and gas rate on the capital investment of venturi scrubber systems for bark/fossil fuel fired boilers.

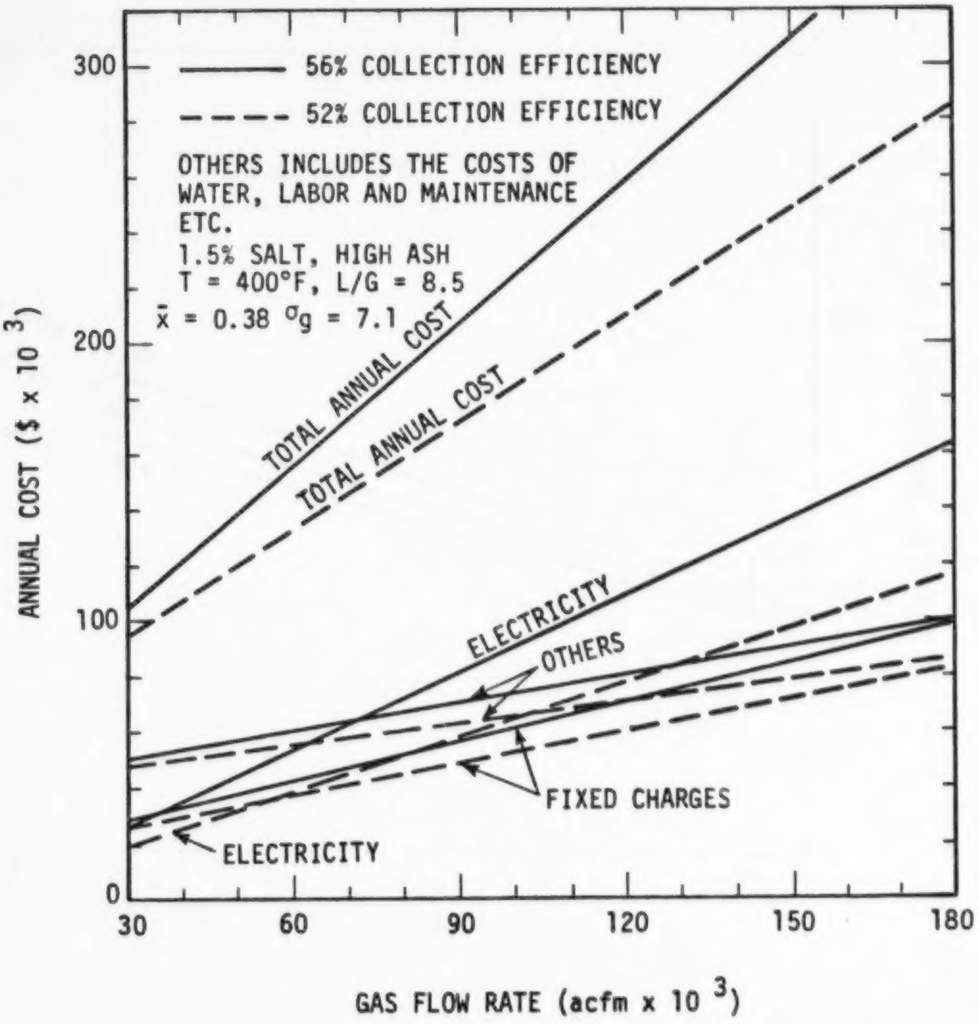

Figure A.3-6. Effects of gas rate, electricity usage, fixed charges and others on the annual costs of venturi scrubber systems for bark/fossil fuel fired boilers.

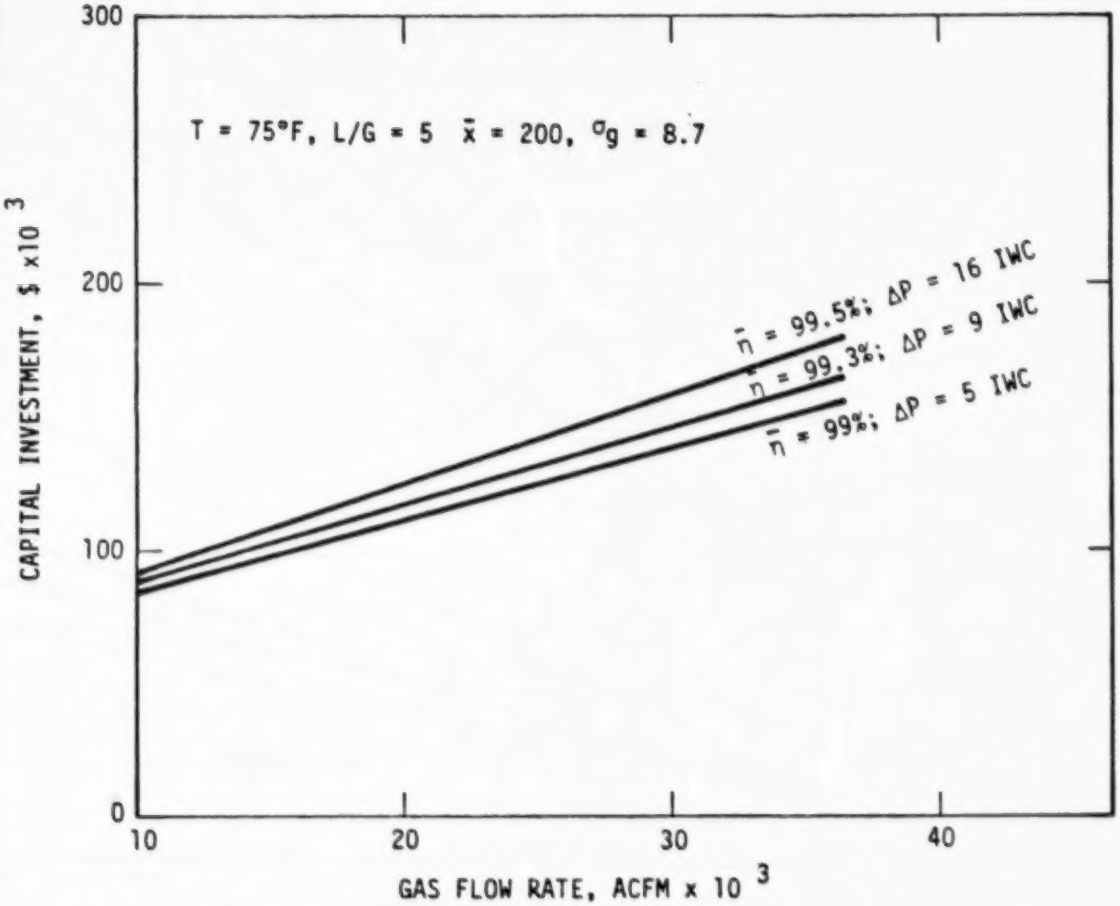

Figure A.3-7. Effects of collection efficiency and gas rate on the capital investment of venturi scrubber systems for stone crushers.

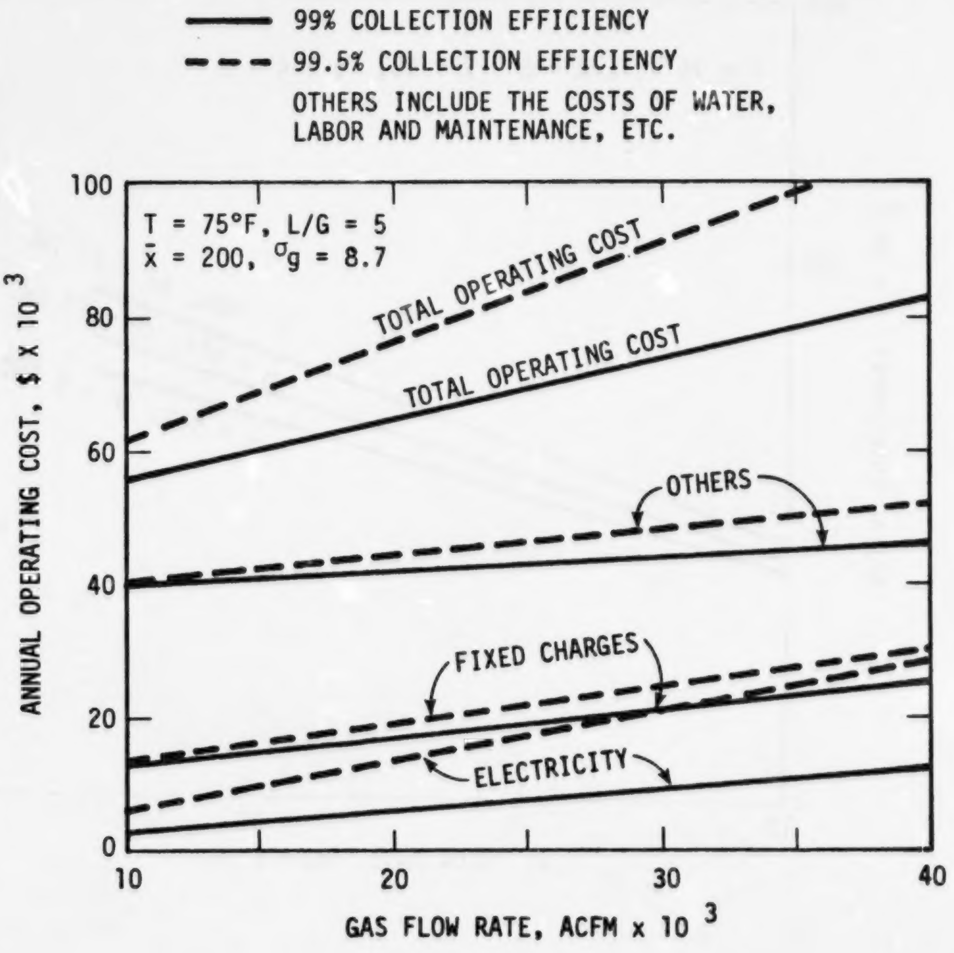

Figure A.3-8. Effects of gas rate, electricity usage, fixed charge, and others on the annual costs of venturi scrubber systems for stone crushers.

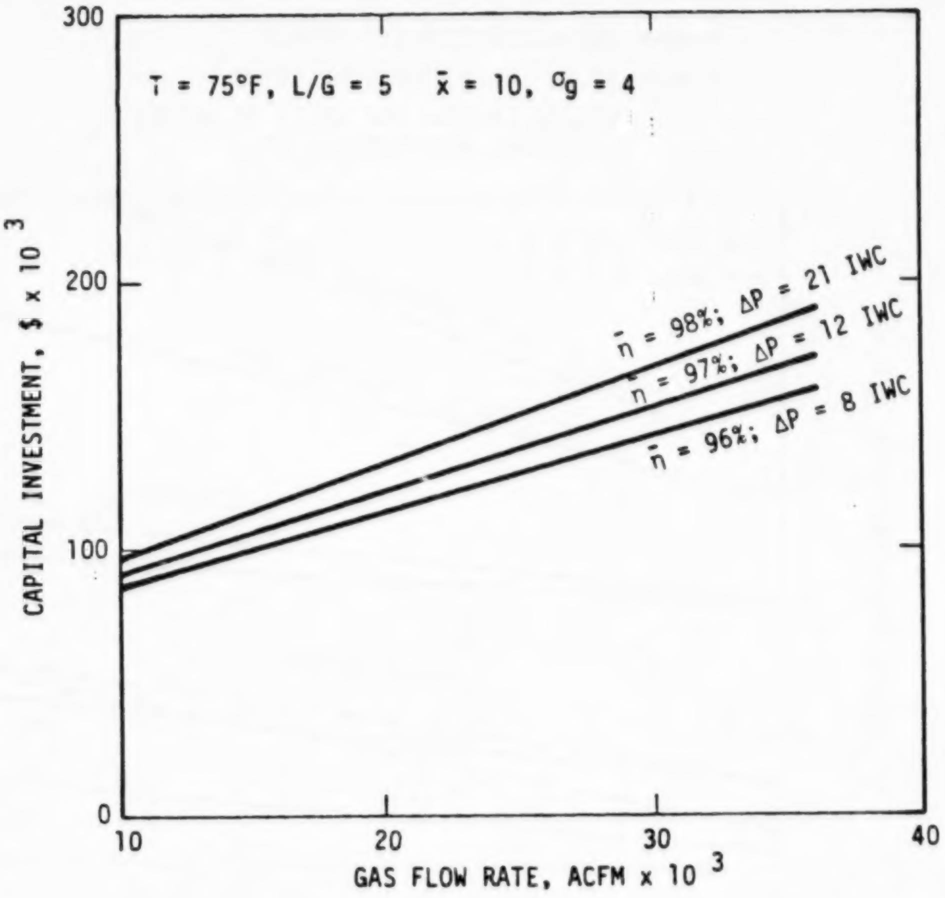

Figure A.3-9. Effects of collection efficiency and gas rate on the capital investment of venturi scrubber systems for stone crushing conveyors.

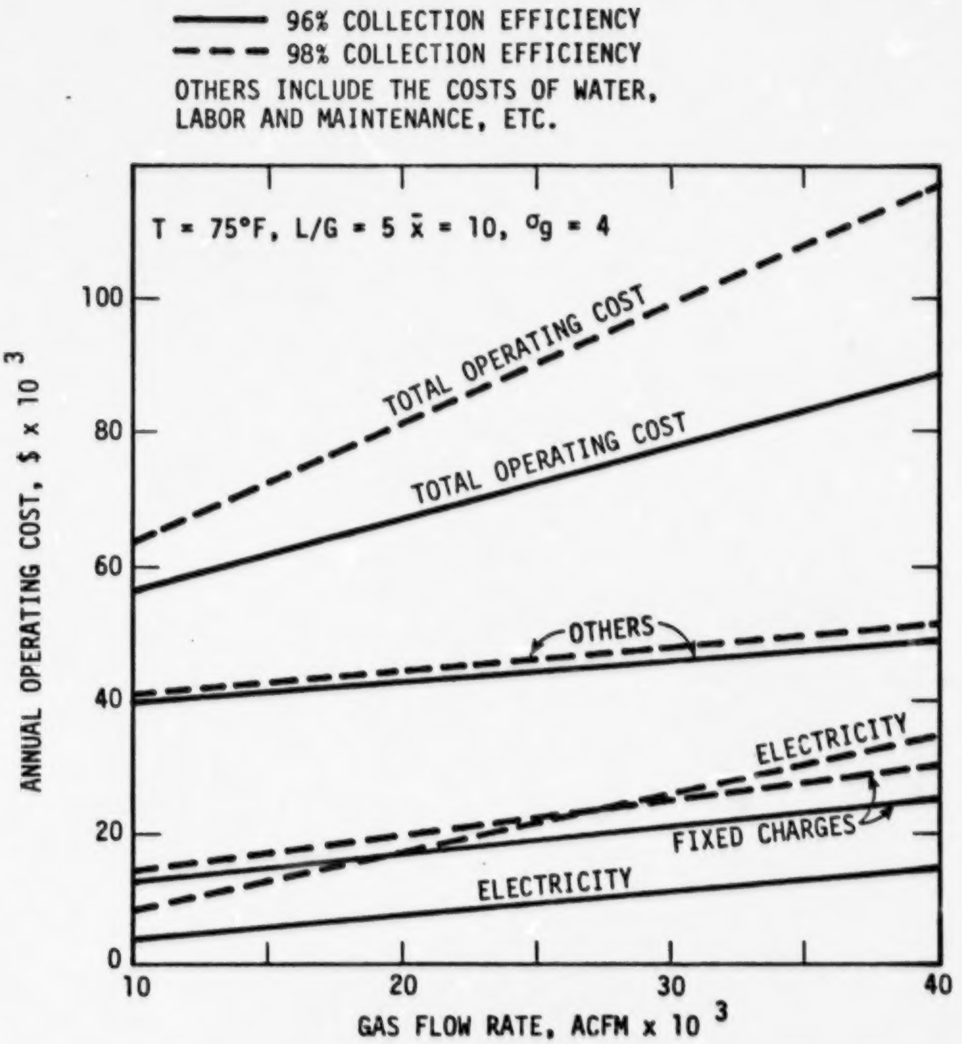

Figure A.3-10. Effects of gas rate, electricity usage, fixed charges, and others on the annual cost of venturi scrubber systems for stone crushing conveyors.

APPENDIX B-1

ELECTROSTATIC PRECIPITATOR SUBSYSTEM AND COMPONENT FUNCTION AND OPERATION

B.1.1 TRANSFORMER-RECTIFIERS

The transformer-rectifier unit consists of a high-voltage transformer, high-voltage silicon rectifiers, and high-frequency choke coils. The unit converts the low-voltage alternating current to high-voltage unidirectional current suitable for energizing the precipitator.

The transformer, rectifiers, and choke coils are submerged in a tank filled with a dielectric fluid. The tank is equipped with high-voltage bushings, liquid level gauge, drain valve, ground lug, filling plug, lifting lugs, and surge arrestors, which discharge any harmful transients appearing across the dc metering circuit to the ground.

The electrical equipment described below comprises the components necessary to produce and control the high-voltage unidirectional power required to energize the electrostatic precipitator. The transformer-rectifier and control unit provide a complete system for energizing with either half-wave or full-wave voltages. Not all precipitator installations incorporate all of these subcircuits, but most will include many of these features; some of the automatic features described below may be done manually on some installations.

A subsystem that automatically maintains and limits optimum current and voltage to the high-voltage transformer, which is connected to the discharge wires.

Silicon controlled rectifiers (SCR's) that provide a wide range of precipitator current and voltage control.

A current-limiting reactor that limits current surges during precipitator sparking.

Automatic restart to initiate system operation after a line voltage failure or temporary ground condition in the precipitator.

Overload protection for the high-voltage rectifiers.

Panels containing component modules; the SCR power circuit, dc overload circuits, relays, control transformers, resistors, main contactor, and current transformer and other components are mounted in the control cabinet and are completely accessible for servicing. Positive ventilation for the control unit is provided by an intake fan located near floor level. Ventilating air is exhausted through an opening (grill-protected) in the upper rear of the control unit.

The transformer enclosure is a square metal housing bolted to the top of the transformer tank. The enclosure protects the transformer bushings and electrical connections from weather and also ensures, via a key interlock system, that none of the electrical connections or bushings can be handled until the associated control cabinet has been de-energized and grounded.

The transformer pipe and guard are used to feed the high-voltage output of the transformer-rectifier to the support bushings, which in turn are connected to the upper high-tension support frame, from which the discharge wires are suspended.

Figures B.1-1 and B.1-2 illustrate vibrator rapper and insulator assemblies and their relationship to the rest of the precipitator system.

B.1.2 AUTOMATIC POWER CONTROLS

During normal operation, optimization of applied power to the precipitator is accomplished by automatic power controls, which vary the input voltage in response to a signal generated by the sparkover rate. Provisions are also included to make the circuit current-sensitive to overload and to allow control in the event that spark level cannot be reached. Although the circuits may vary among installations, many of the features described below are common. An SCR mainline control diagram is presented in Figure B.1-3 to illustrate operation of the automatic power control system.

When the circuit breaker and control circuit on/off switch are closed, power flows through the current-limiting reactor, current transformer, and current signal transformer to the primary of the high-voltage transformer. The SCR's act as a variable impedance and control the flow of power in the circuit. An SCR is a three-junction semiconductor device that is normally an open circuit until an appropriate gate signal is applied to the gate terminal, at which time it rapidly switches to the conducting state. Its operation is equivalent to that of a thyrotron. The amount of current that flows is controlled by the forward blocking ability of the SCR's. This blocking ability is controlled by the firing pulse to the gate of the SCR. The

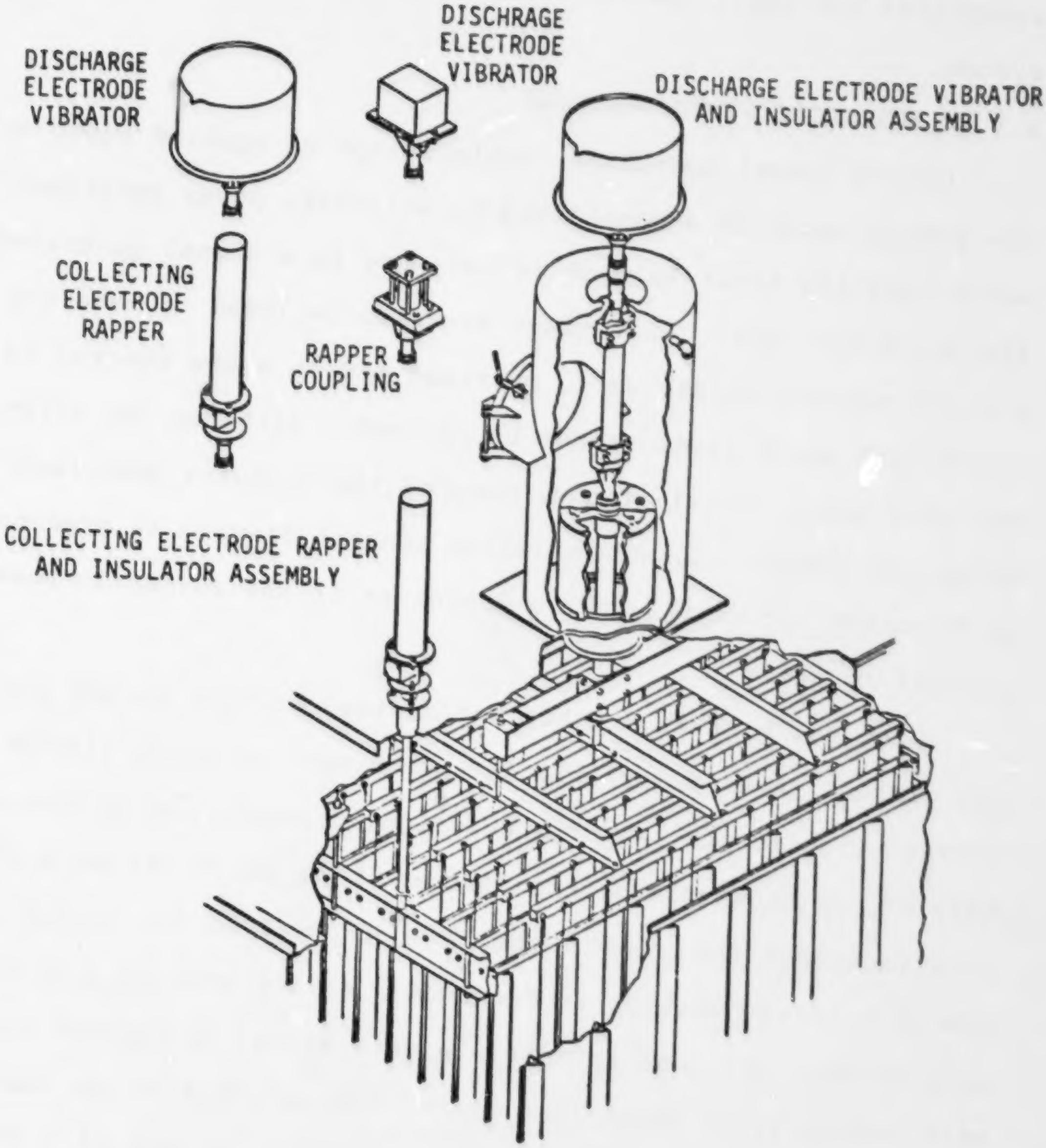
DISCHARGE ELECTRODE VIBRATOR
DISCHRAGE ELECTRODE VIBRATOR
DISCHARGE ELECTRODE VIBRATOR AND INSULATOR ASSEMBLY
COLLECTING ELECTRODE RAPPER
RAPPER COUPLING
COLLECTING ELECTRODE RAPPER AND INSULATOR ASSEMBLY

Figure B.1-1. Insulator, vibrator-rapper assembly, and precipitator high-voltage frame.

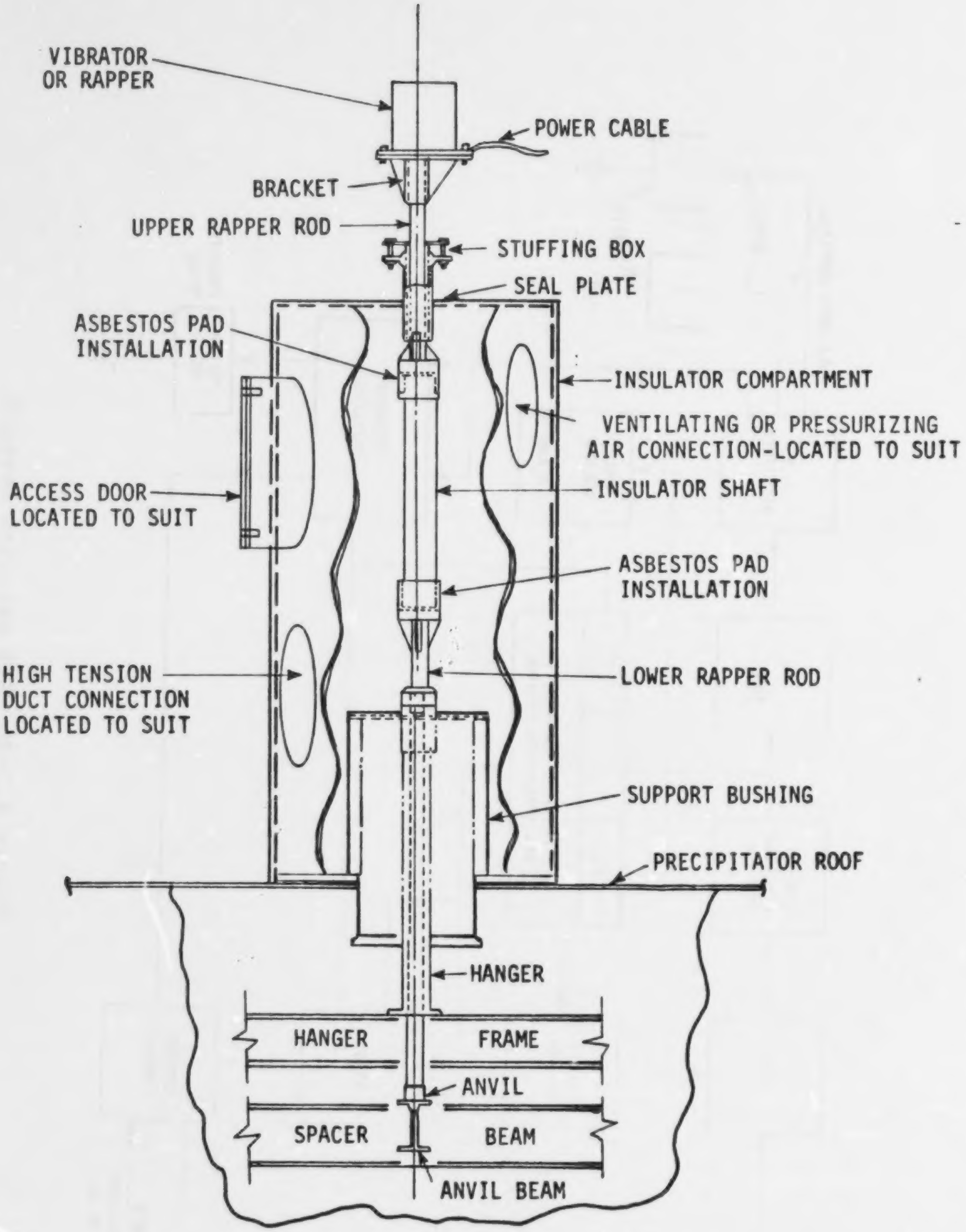
VIBRATOR OR RAPPER
POWER CABLE
BRACKET
UPPER RAPPER ROD
STUFFING BOX
SEAL PLATE
ASBESTOS PAD INSTALLATION
INSULATOR COMPARTMENT
VENTILATING OR PRESSURIZING AIR CONNECTION-LOCATED TO SUIT
ACCESS DOOR LOCATED TO SUIT
INSULATOR SHAFT
ASBESTOS PAD INSTALLATION
HIGH TENSION DUCT CONNECTION LOCATED TO SUIT
LOWER RAPPER ROD
SUPPORT BUSHING
PRECIPITATOR ROOF
HANGER
HANGER
FRAME
ANVIL
SPACER
BEAM
ANVIL BEAM

Figure B.1-2. Precipitator insulator and vibrator-rapper assembly.

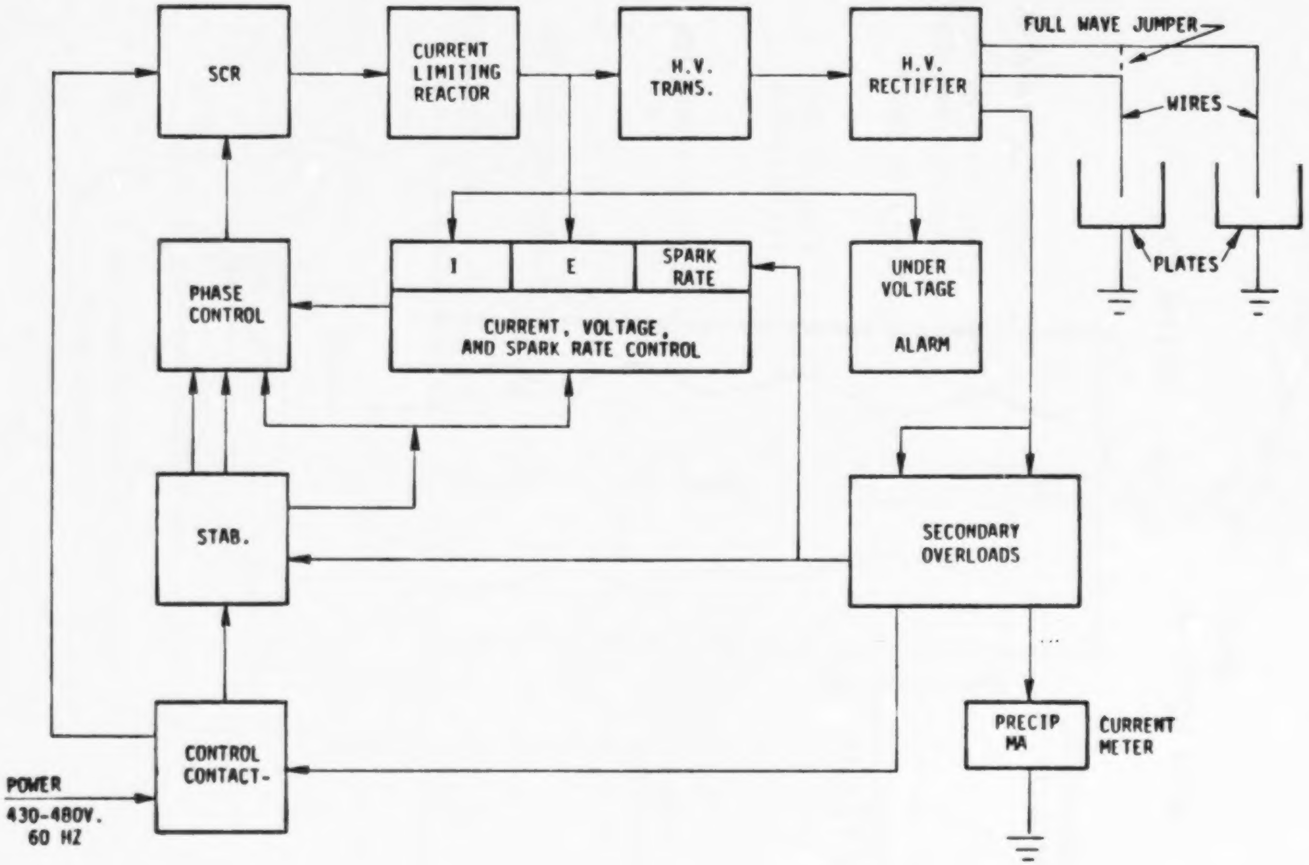
SCR
CURRENT LIMITING REACTOR
H.V. TRANS.
H.V. RECTIFIER
FULL WAVE JUMPER
WIRES
PLATES
PHASE CONTROL
I
E
SPARK RATE
CURRENT, VOLTAGE, AND SPARK RATE CONTROL
UNDER VOLTAGE ALARM
STAB.
SECONDARY OVERLOADS
CONTROL CONTACT-
POWER
430-480V. 60 HZ
PRECIP MA
CURRENT METER

Figure B.1-3. SCR mainline control.

current-limiting reactor reshapes the current wave form to essentially a sine wave and limits peak current due to sparking.

The firing circuit module provides the proper phase-controlled signal to fire the SCR. The timing of the signal is controlled by 1) the potentiometer built into the module, 2) the signal received by the automatic controller, and 3) the signal received by the spark stabilizer.

The automatic control circuit performs three functions: spark control, current-limit control, and voltage-limit control.

Spark control is based on storing electrical pulses in a capacitor for each spark occurring in the precipitator. If the voltage of the capacitor exceeds the preset reference, an error signal will phase the mainline SCR's back to a point where the sparking will stop. Usually this snap-action type of control will tend to overcorrect, resulting in a longer downtime than is desirable. At low sparking rates, about 50 sparks per minute, the overcorrection is more pronounced, resulting in reduced voltage for a longer period, with subsequent loss of dust and reduced efficiency.

Proportional control is also based on storing of electrical pulses for each spark occurring in the precipitator. The phase-back of the mainline SCR's, however, is proportional to the number of sparks in the precipitator. The main advantage of proportional control over spark control is that the precipitator determines its own optimum spark rate, based on four factors: temperature of the gas, dust resistivity, dust concentration, and internal condition of the precipitator. In summary, with proportional spark rate control, the precipitator determines the optimum operating parameters. With conventional spark control, the operator selects the operating parameters, which may not be optimal.

Some precipitators operate at the maximum voltage or current settings on the power supply with no sparking. In collection of low-resistivity dusts, where the electric field and the dust deposit are insufficient to initiate sparking, the no-spark condition may arise. The fact that the precipitator is not sparking does not mean necessarily that the unit is underpowered. The unit may have sufficient power to provide charging and electric fields without sparking.

The voltage-limit control feature of the automatic control module limits the primary voltage of the high-voltage transformer to its rating. A transformer across the primary supplies a voltage control, as in the case of the current limit. The voltage control setting is adjusted for the primary voltage rating of the high-voltage transformer. When the primary voltage exceeds this value, a signal is generated that retards the firing pulse of the firing module and brings the primary voltage back to the control setting.

For current-limit control, a transformer in the primary circuit of the high-voltage transformer monitors the primary current. The voltage from this transformer is compared with the setting of the current control, which is adjusted to the rating of the transformer-rectifier unit. If the primary current exceeds the unit's rating, a signal is generated, as with spark control, which retards the firing pulse of the firing circuit and this brings the current back to the current-limit setting.

With all three control functions properly adjusted, the control unit will energize the precipitator at its optimum or maximum level at all times. This level will be determined by conditions within the precipitator and will result in any one of the three automatic control functions operating at its maximum, i.e., maximum voltage, maximum primary current, or maximum spark rate. Once one of the three maximum conditions is reached, the automatic control will prevent any increase in power to reach a second maximum. If changes within the precipitator so require, the automatic control will switch from one maximum limit to another.

Other features include secondary overload circuits and an undervoltage trip capability in the event that the voltage on the primary of the high-voltage transformer falls below a predetermined level and remains below that level for a period of time. A time-delay relay is also used to provide a delay period in the annunciator circuit while the network of contacts is changing position for circuit stabilization due to an undervoltage condition.

B.1.3 VIBRATORS

The purpose of a vibrating system is to create vibrations in either the collecting plates or the discharge wires to dislodge accumulations of particles so that the plates or wires are kept in optimum operating condition.

The vibrator is an electromagnetic device, the coil of which is energized by alternating current. Each time the coil is energized, the vibration set up is transmitted to the high-tension wire supporting frame and/or collecting plates through a rod. The number of vibrators depends on the number of high-tension frames and/or collecting plates in the system.

The control unit contains all devices for operation of the vibrators, including means of adjusting the intensity of vibration and the vibration period. Alternating current is supplied to the discharge wire vibrators through a multiple cam-type timer to provide the sequencing and time cycle for energization of the vibrators.

For each installation, a certain intensity and time period of vibration will produce the best collecting efficiency. Insufficient vibrating intensity will result in heavy buildups of dust on the discharge wires which can cause the following adverse operating conditions.

> It reduces the spark-over distance between the electrodes, thereby limiting the power input to the precipitator.
>
> It tends to suppress the formation of negative corona and the production of unipolar ions required for the precipitation process.
>
> It alters the normal distribution of electrostatic forces in the treatment zone. Unbalanced electrostatic fields can cause the discharge wires and the high-tension frame to oscillate.

B.1.4 RAPPERS

The rapper equipment is a completely electrically operated system for continuously removing dust from the collecting plates within the precipitator. The system is composed of a number of magnetic-impulse, gravity-impact rappers that are periodically energized to rap the collecting plates for removal of dust deposits. The main components of the system are the rappers and the electrical controls.

The magnetic-impulse, gravity-impact rapper is a solenoid electromagnet consisting of a steel plunger surrounded by a concentric coil, both enclosed in a watertight steel case. The control unit contains all the components (except the rapper) needed to distribute and control the power to the rappers for optimum precipitation. The electrical controls provide a number of separate adjustments so that all rappers can be assembled into a number of different groups, each of which can be independently adjusted from zero to maximum rapping intensity.

B.1.5 UPPER PRECIPITATOR

On positive or negative pressure installations a pressurizing fan is supplied (located on the cold roof) to force air into the top housing and down through the support bushings. This air prevents the process gases in the precipitator from entering the top housing and contaminating the support and high-tension frame vibrator-rapper insulators. Electric heaters are also used to prevent condensation buildup on the porcelain bushings, thereby preventing electrical short circuits which may damage the bushings.

In place of a top housing, some installations have insulator compartments. The insulator compartment is a steel enclosure that surrounds the high-tension frame support insulators and rapper rod insulators. Fans are provided to prevent condensation of moisture on the high-voltage support insulator, and sometimes electric heaters are installed near each bushing in each insulator compartment.

The purpose of the high-tension anvil beam, which is part of the high-tension frame, is to transfer the impact of the high-tension vibrator to the discharge wires.

B.1.6 DISCHARGE WIRES

The discharge electrodes are small-diameter wires suspended from a structural steel wire supporting frame, held taut by individual cast iron weights at the lower end and stabilized by a steadying frame at the top of the cast iron weights. Unshrouded and shrouded discharge wires are illustrated in Figures B.1-4 and B.1-5, respectively.

B.1.7 COLLECTING PLATES

The gas flows horizontally in the precipitator through individual gas ducts formed by the collecting plates. The discharge wires are located midway between the plates for the purpose of ionizing the gases and imparting an electric charge to the dust particles. It is important that the plate and wire spacing be held to close tolerances. Figure B.1-6 illustrates the type of collection plate used in many electrostatic precipitators manufactured by Research-Cottrell.

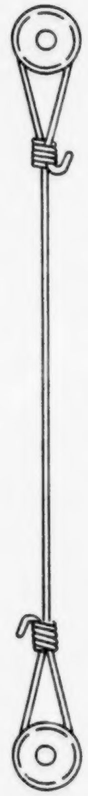

Figure B.1-4. Discharge electrode unshrouded

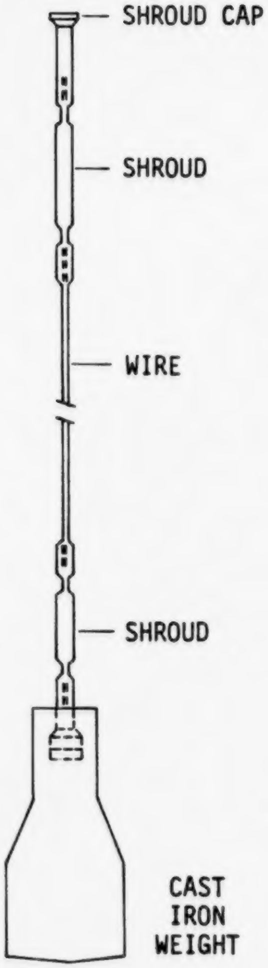
SHROUD CAP
SHROUD
WIRE
SHROUD
CAST IRON WEIGHT

Figure B.1-5. Discharge electrode shrouded

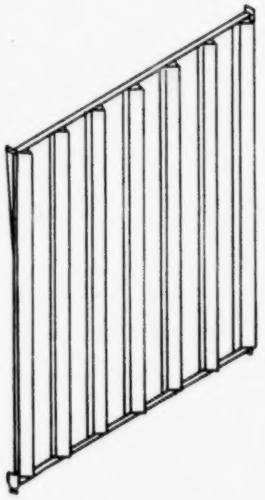

Figure B.1-6. Precipitator collecting electrodes

B.1.8 LOWER PRECIPITATOR

The lower steadying frame limits or restricts the horizontal movement of the discharge wires.

APPENDIX B-2. PRECIPITATOR PREOPERATION CHECKLIST

1.) General

Before start-up of the precipitator(s) and auxiliary equipment, a complete check and visual inspection of the following items should be performed.

2.) Precipitator

	Check	Initial	Date	Recheck	Remarks
a) Duct spacing					
b) Collecting plates					
° Bowing					
° Bellying					
° Supports					
° Spacer bars					
° Corner guides					
c) Gas sneakage baffles					
d) Anti-swing devices					
e) Hoppers					
° Dust level indicators					
° Outlet connections					
° Access doors					
° Poke holes - anvils					
° Vibrators					
f) Insulator housing					
° Support bushings					
° Access doors					
° Ventilation system					
° Bushing connections					
° Bushing heaters					

	Check	Initial	Data	Recheck	Remarks
g) Flues					
• Nozzle connections					
• Expansion joints					
• Louver dampers					
• Guillotine dampers					
• Perf. distribution plates					
h) Line voltage					
• 460/480 volts-60 Hz					
• 575 volts - 60 Hz					
• 120 volts					
• Line matching transformer					
i) Discharge electrode wires					
• Upper steadying frame					
• Lower steadying frame					
• Hanger pipes					
• Lifting rods					
• C.I. weights - 15 25 35					
j) High-tension guard					
• Installation					
• Vent ports open					
• Ground connections					
k) Drag bottom conveyor					
l) Wet bottom agitators					
m) Heat jacket system					
• Recirculating fan					
• Electric heater - kW					
• Steam heater coils					
• Temperature transmitters					
• Pneumatic recorders					
• Steam control valve					
• Starters - pushbuttons					
• Thermostats					
n) Roof enclosure					
• Ventilation					
• Air conditioning					
• Monorail system					
• Roof exhausters					
• Louvers					
• Heaters					

	Check	Initial	Data	Recheck	Remar
o) Gaskets for high temperature					
3.) Auxiliary Equipment					
a) Transformer-rectifier units					
° Surge arrestor gap					
° Transformer liquid level					
° Ground connections					
°° Precipitator					
°° Transformer					
°° Rectifier					
°° H.T. bus duct					
°° Conduits					
°° FW/HW switch box					
°° Alarm connections					
°° Contact making thermometer					
° Ground switch operation					
° High-voltage connections					
° Telephone jacks					
° Sound power jacks					
° Resistor board					
° Space heaters					
b) Rectifier control units					
° Controls grounded					
° Connections to equipment					
° Space heaters					
° Internal light and switch					
° Alarm connections					
° Space heaters					
c) Rapper control unit					
° Connections					
° Lights					
° Space heaters					
d) Vibrator control unit					
° Connections					
° Lights					
° Space heaters					

	Check	Initial	Data	Recheck	Remarks
e) F.D. Ventilation controls					
° Motor					
° Starters					
° Pushbutton stations					
° Alarm connections					
° Filters					
f) Electric heater controls					
° Hoppers					
° Insulator housing/ compartment					
° Roof enclosure					
° Control house					
g) Control house					
° Heaters					
° Ventilation					
° Motor control centers					
° Distribution panelboards					
° Lighting panelboards					
° Starters					
h) Screw conveyors					
i) Rotary feeder valves					
j) Zero speed detectors					
k) Speed reducers					
l) Trough type hoppers					
m) Inner doors - drag bottom level					
n) Air vibrators-Navco 3 in.					
o) Air vibrator controls					
p) Water spray piping					
q) Pillow block assembly					

	Check	Initial	Date	Recheck	Remarks
r) Automatic back draft dampers					
s) Filter boxes - filters					
t) Butterfly dampers					

APPENDIX B-3

ELECTROSTATIC PRECIPITATOR INSPECTION, MAINTENANCE, AND TROUBLESHOOTING PROCEDURES

B.3.1 TRANSFORMER-RECTIFIER SETS AND ASSOCIATED EQUIPMENT AND CONTROLS

Check the liquid level in the transformer weekly. If it is low, fill the tank to the level indicated on the gauge with the dielectric liquid specified on the nameplate. Dielectric fluid should be handled with extreme caution.

Clean high-tension insulators, bushings, and terminals during each outage to minimize surface leakage. Glazed porcelain is best cleaned with a damp cloth and a nonabrasive cleaner.

Once each year or more often, clean the contacts of relays and dress them with a fine grade of crocus cloth.

Check the dustop filter weekly. The air filter assembly, easily attached and convenient for servicing, is mounted on the control cabinet.

Transformer Enclosure

Inspect all bushings and insulators. Replace those that are damaged; clean those that are dusty with a nonabrasive cleaner.

Clean all interlocks and lubricate with powdered graphite to ensure smooth and proper action.

Lubricate all bearing points on the ground-operator lever, connecting rods, and bevel gears.

Check all electrical connections to ensure that they are corrosion-free and tight. Loose electrical connections can cause electrical erosion of connections and failure of metering circuits and electrical components in both the control cabinet and transformer.

Pipe and Guard

Remove all internal rust and/or scaling. Rust appearing on the internal walls of the guard could peel off and fall against the pipe, causing a ground on the secondary of the transformer.

Check the condition of the wall and post insulators for signs of electrical tracking (arcing), dust buildup, and cracked insulators. Clean or replace parts as required.

Check the pipe to ensure that all connections to wall bushings and post insulators are tight and that the pipe elbows used to redirect the pipe at various turns in the guard are tight and secure.

Ensure against water leakage by checking and maintaining the seal on the inspection plates of the pipe and guard.

When replacing the inspection covers, be certain to reinstall the ground jumper between the guard and cover plate; this ensures that any static charge or high-voltage leak goes to ground.

B.3.2 VIBRATORS

Inspect each vibrator for proper gas setting.

Inspect boot seal for holes or tears and replace if necessary.

Inspect the service sheet gasket between the guide plate and the mounting nipple for signs of deterioration and replace if necessary.

If boot seal or service sheet gasket has deteriorated, dismantle the vibrator-rapper rod assembly and inspect the vibrator rod nipple for dust accumulation. Packed dust in this area will dampen the vibrations to the discharge wires and cause excessive dust accumulation, close electrical clearances, and reduced precipitator performance. Check the area where the vibrator rapper rod passes through the packing ring retainer plate for dust or for sign of inleakage of air and/or water. This condition is indicative of a loose retainer plate providing an inadequate seal between the packing and the vibrator-rapper rod or of failure of the package rings. A loose retainer plate should be tightened and in case of gas leakage, the packing should be replaced.

B.3.3 PLATE RAPPERS

Check the rapper assemblies periodically for any possible binding of the plunger or misalignment of assembly. The maximum amount of energy can be transmitted from coil to plunger only when the plunger is properly located with respect to the coil. Any deviation will decrease the energy transmitted. Adjusting bolts allows changes of the distance between the lower casing and the mounting and thereby allows variation of the plunger insertion in the coil.

If the boot seal or service sheet gasket has deteriorated, dismantle the vibrator-rapper assembly and inspect the rapper rod sleeve for dust accumulation. Packed dust in this area will dampen the shock wave to the collecting plate and cause excessive dust accumulation on the plates (wires). [A boot seal is the rubber seal that is stretch-fitted over the end of the rapper rod. On negative-pressure installations, the boot seal prevents air and water from entering the precipitator chamber through the rapper rod guide sleeve. On positive-pressure installations, the boot seal prevents precipitator gases from flowing up the rapper and guide sleeve and entering the rapper coil tube.]

Inspect striking end of plunger to ensure that the end has not been flared or otherwise deformed due to excessive height in its lift and/or misalignment.

When reassembling the rapper assembly after maintenance has been performed, make certain that the coil and coil cover are plumb and level, and that the plunger is properly aligned in a vertical plane on the rapper rod.

The maintenance checks outlined above apply also to wire rappers.

B.3.4 UPPER PRECIPITATOR

Top Housing

Inspect the fan to ensure that it is working and that the filters are in good condition.

Inspect vent elbows for accumulation of foreign matter, which would reduce or cut off the air flow.

Check access doors, inspecting the gaskets for signs of deterioration and leaks. Replace defective gaskets and lubricate door lugs and hinges as required.

Check that interlocks are clean, and lubricated with powdered graphite.

Inspect the upper rapper-rod vibrator on the high-tension frame to ensure that it is centered in its guide nipple and that no dust has packed between the nipple and the rapper-vibrator rod. If the rapper-vibrator rod needs to be centered in the nipple, cover the insulator with an asbestos blanket, and with a torch cut the nipple loose from the cold roof. Reposition the nipple, centering the rod, and reweld the nipple to the cold roof. Care must be taken that the new weld is a complete seal; water and ambient air could flow through pinholes and contaminate the insulators.

Note: Whenever, it is necessary to do any welding on the high-tension wire supporting frame, the electrical bus connection to the high-tension support bushing should be disconnected. A heavy, temporary ground, sufficient to carry total welding current, should be solidly connected to the high-tension frame. The disconnected bushing should be securely grounded at both ends, i.e., in the rectifier ground switch enclosure and at the support bushing end.

Insulator Compartments

Energize high-tension frame vibrators and check for smooth operation. Check field wiring and vibrator control cabinet if an inoperative vibrator is found. Vibrator insulator nuts and all pipe plugs should be secure.

Check all nipples and seals.

Inspect all dampers in the duct connections to the compartments to ensure that they are in the open position. Operate pressurizing fan and check that air is flowing uniformly into each insulator compartment.

The vent elbow should be equipped with a pipe plug unless the installation is operating under negative pressure. If the installation is under negative pressure, there should be no plug. Inspect the elbow for dust and/or other foreign material.

Inspect the pipe and guard through the inspection hatch to ensure that the inside surface is free from dust accumulation and/or rust and scale. Remove all dust accumulations and/or rust and scale buildups to prevent high-voltage arcing from the pipe to the guard. Inspect insulators to ensure that they are free from cracks, chips, and dust accumulations. Replace any cracked or chipped insulators and clean dirty insulators with a nonabrasive cleaner.

Inspect the gasket on the inspection door for deterioration and leaks; replace worn or leaky gaskets. Make sure that all bolts are in place and securely fastened. Determine that interlock is operable and well-lubricated with powdered graphite.

Inspect upper vibrator-rapper rod - see Section 3.1.3.

Inspect the vibrator-rapper rod insulator for dust accumulation, chips, cracks, and electrical tracking. Electrical tracking that has not damaged the glazed surface of the insulator and dust accumulations should be cleaned off with a nonabrasive cleaner. Replace cracked, chipped, or glaze-damaged insulators.

Inspect the area between the vibrator-rapper rod and the hanger pipe for packed dust accumulations. Remove any accumulation as it tends to dampen the vibration transmitted to the upper high-tension frame. Check to see that the vibrator-rapper rod is centered in the support pipe. If the support pipe is off center, chances are that the weld between the lower vibrator-rapper rod and the upper high-tension frame has broken. Recenter the rod and reweld it to the high-tension frame. As with the upper vibrator-rapper rod, inspect the insulator clamp, ensuring that all bolts are in place and tight.

Check the high-tension frame support pipe. Inspect the round nut screwed onto the support pipe to prevent pipe movement.

Remove the cover plates and inspect the inside and outside surfaces of the support insulator for dust accumulations, electrical tracking, cracks, and chips. Dust accumulations and electrical tracking that have not damaged the glazed surface of the insulator should be cleaned with a nonabrasive cleaner.

Plate Hanger Anvil Beam

Inspect the anvil beam hanger rod clips to ensure that they are straight. Excessively heavy plate vibrating-rapping can in time cause these clips to bend, causing the plate bank to shift out of alignment. This shift results in electrical clearances out of tolerance and reduced precipitator performance.

Inspect the hanger rods to ensure that none are broken, missing, or bent. Broken, missing, or bent hanger rods usually cause out-of-tolerance electrical clearance and reduced precipitator performance. Replace any defective hanger rods.

Inspect the area behind the plate hanger anvil beam for packed dust. Remove dust, since it can force the beam out of plumb.

Inspect the weld between the vibrator-rapper rod and the anvil beam. If this weld is broken or cracked, it should be replaced.

Upper High-Tension Frame

Check bolts and welds on the high-tension frame.

Replace broken, bent, or missing support rods.

Check wire support angles for broken welds where they attach to the spacer beam. Repair broken welds, making sure that the wire support angles are parallel and on 9-inch centers (assuming 9 inch plate-to-plate spacing).

Check to determine whether the high-tension frame is level both perpendicular and parallel to the gas flow. If the frame is not level in the direction of gas flow, adjust at the appropriate high-tension frame support rods. If the frame is not level perpendicular to the gas flow, adjust at the appropriate high-tension frame hanger pipes.

Check for excessive accumulation of dust on this frame. Accumulations are excessive if they interfere with specified clearances of 4-1/2 inches ± 1/4 inch between the discharge wires and collecting plates or if they create a clearance of less than 4-1/2 inches between the high-tension frame and any other grounded surface (assuming 9 inch plate-to-plate spacing).

B.3.5 DISCHARGE WIRES

Whenever possible, determine the condition of the discharge wires with regard to dust buildup. The amount of buildup will indicate whether the high-tension vibrators are operating at the proper intensity.

The discharge wires should be kept as clean as is practical.

Inadequate vibrating-rapping of the discharge wires can result in heavy dust buildup, with localization of the corona current and excessive sparking.

A deposit on the discharge wires results from many things, including poor gas distribution and characteristics of the dust. Doughnut-shaped deposits often are formed. They are composed generally of finer dust particles. Deposits on the discharge wires do not necessarily result in poor performance, although depending on resistivity, power supply range, and uniformity of the deposit, they can reduce efficiency.

The discharge wires should be perfectly centered between the plates from top to bottom for optimum precipitator operation. Any broken discharge wires should be removed and if time permits, replaced with new wires. Since a cast iron weight is connected to each wire at its lower end, a resistance will be felt when pulling on the wire. A wire that gives no resistance is broken.

Broken wires can sometimes be seen from catwalks located between the collecting plate banks. With a flashlight, look down each duct noting any bottle weight that is hanging on its bottle guide and any wires that are out of alignment.

The location of a broken wire that is removed but not replaced should be recorded on a permanent log sheet. This recording will save time during future outages when time permits the installation of a new wire. A record of broken wire locations is also helpful in determining the cause of wire breakage, i.e., if a number of wires break in the same area of the precipitator, there are alignment problems. If the wire breakage is random, the breakage is probably caused by dust buildups on wires or plates.

The damaged wire may be cut away and the replacement wire brought into the precipitator through the top upper high-tension frame area, placed in the proper duct, lowered into place, and attached.

B.3.6 COLLECTING PLATES

Whenever the precipitator is out of service and internal inspections are possible, the collecting plates should be checked for proper alignment and spacing. Check all hangers. Make sure that spacers at the bottom of the plates do not bind plates to prevent proper rapping. Check the lower portion of all plates and the portion of plates adjacent to any door openings for signs of corrosion. If corrosion is present, it usually indicates air inleakage through hoppers or around doors.

Observe the dust deposits on the collecting plates before starting any cleaning of the precipitator. The normal thickness of collected dust is about 1/2 inch with occasional buildups of 1/4 inch. If the buildup exceeds this amount, the intensity of the plate vibrating-rapping should be increased. If the collection plates are almost metal clean, this may be an indication of high gas velocity, extremely coarse dust, too high a vibrating-rapping intensity, or too low an operating voltage for good precipitation. This condition may be noted if a section has been shorted out prior to the inspection.

The plate may be in effect removed from service by removing the discharge wires surrounding it. When bellying or bowing of the plates is noted, the concave side of the plate may be heat-treated with a torch, depending upon the severity of the deformity.

B.3.7 LOWER PRECIPITATOR STEADYING FRAME

Inspect the steadying bars for cracked or broken welds where they mount to the steadying bar support. Perform any needed repairs.

Make sure that the lower steadying frame is level both in the direction of gas flow and perpendicular to gas flow. If the frame is not level, readjust the support wires, adjusting both until the frame is level. Place equal tension on each of the support wires connected to adjusting bolts, since slack wires will cause excessive sparking.

Inspect the steadying frame for downward bow in the steadying bars (usually occurs after operating the precipitator at over-design temperatures). Downward bows can usually be removed by cutting a wedge-shape slot in the vertical member of the steadying bar angle, pushing with jacks or pulling with a block and tackle until the frame is straight, then welding an additional piece of angle iron inside the steadying bar angle and across the wedge slot.

Inspect the steadying frame for twisting. A twisted frame causes excessive weight on some wires and slackness in others. To straighten a twisted frame, grasp one end of the frame and twist the frame until that end is straight and level. While holding the frame in this position, weld the frame to the hopper walls. Repeat for the other end of the frame. Once the frame has been welded to the hopper walls and is straight and level, using a torch, stress-relieve the frame by heating each connection between the steadying bar supports and the steadying bars until it glows to a cherry red. After all joints have been relieved, allow the frame to cool, then cut it free of the hopper walls. If the frame is still twisted, repeat the procedure. If after the second heating the frame is still twisted, a new frame will have to be installed.

When checking the lower steadying frame anti-sway insulators, check the surface for dust accumulation, glaze damage caused by electrical tracking, cracks, and chips. Insulators with dust accumulation and/or electrical tracking that has not damaged the glazed surfaces may be cleaned with a nonabrasive cleaner. Cracked, chipped, broken, or glaze-damaged insulators may be replaced.

B.3.8 DUST COLLECTION POINT

In electrostatic precipitators servicing recovery furnaces, the precipitator bottom can be one of two designs -- dry and wet. The dry drag bottom can be constructed as a flat bottom collecting chamber underneath the precipitator plates. From there the collected material is removed by means of drag scraper and screw conveyor and finally discharged into a rotary valve. The use of trough hoppers with screw conveyors and rotary discharge valves is another method of collecting dust from dry bottom electrostatic precipitators. The wet bottom construction is associated with the conventional recovery process.

Dry Drag Bottoms

It is extremely important that all bearings be lube-purged after every precipitator washdown. In the worm gear speed reducer, the oil case should be thoroughly flushed with a light flushing oil before refilling. An oil change every two to three months is recommended thereafter. Check the oil level in both the high speed and low speed chambers before operating. Check periodically, with reducer at rest, to determine whether the oil is at the proper level. The slow speed shaft bearings should be lubricated with a lithium based grease. The motor bearings are prelubed prior to shipment. However, where the motor is used constantly in a dirty or wet environment, it is advisable to add one quarter ounce of lithium based bearing grease per bearing every three months. Where it is necessary to add grease, stop the motor. The Rex bearings should be examined and relubricated at least every six months. The Roller chain should be lubricated manually with a brush or spout type oil can maintaining a clean oil film at all load carrying points where relative motion occurs to assure maximum operating efficiency. These points are between the pin and bushing, bushing and roller, and the roller and the sprocket teeth. Oil should be directed to the inside of the lower span of chain in the spaces between the side bars. The motor coupling is prelubed, but periodic inspections should be made to assure that the coupling contains lubrication.[1]

Wet Bottom

During periodic precipitator shutdowns, all of the liquor should be drained into the wet bottom pan. In this way all accumulations of saltcake present on the floor of the wet bottom can be removed. Periodic check should be made of the structural soundness and tightness of the acid proof lining on the vertical sides of the pan. Check the oil level in the gear reducer of the agitator drive. The bearings should be greased and checked. The wet bottom liquor level control consists of an external float chamber with a float actuated level controller. Occasionally, soap will accumulate in the float chamber which should be cleaned out at frequent intervals. To prevent the black liquor from congealing in the float chamber, it is important that a small supply of hot liquor be continually fed to the float tank.

Hoppers

The dust collecting system in bark and combination bark/fossil fuel fired boilers consists of pyramidal and trough hoppers. It is extremely important to establish a regular schedule of hopper emptying at the start of operation and adhere to it as closely as possible, preferably once a shift. If the hoppers are allowed to fill over a 24-hour period or longer, the electrical components may short out and precipitation will cease. Also, if a fly ash hopper is allowed to stand for more than 24 hours, the dust tends to pack, cool off, and absorb some moisture from the gases. The principal problems with hoppers are 1) corrosion and 2) difficulty with free-flowing of the dust from the hoppers. Both problems may be partially overcome by proper steam tracing and heat insulation of the hopper exterior, subsequent care that a constant steam supply to the hopper coils is being maintained, and that damaged heat insulation is properly repaired. Any abnormal buildups should be removed. If this condition becomes chronic, it is an indication of low operating temperatures, insufficient heat insulation, or inadequate hopper emptying. Also it should be noted that because of the carbonaceous nature of this dust, excessive accumulation in pyramidal hoppers can become a fire hazard.

Screw Conveyor System

In recovery furnace applications saltcake is normally removed by means of screw conveyors. In the bark and combination bark fossil fuel-fired boilers, dust is removed by a vacuum conveying system. The dust is aspirated out, mixed with water to form a slurry, and then transported away. In the screw conveyor system it is important to establish routine periodic inspections of the entire conveyor to insure continuous maximum operating performance. Important items to check are intake and discharge points, flight thickness at the outer edge, and condition of bearings.

B.3.9 PRECIPITATOR SHELL

The flue gases, emanating from the kraft pulp mill process, contain certain acidic constituents which are extremely corrosive to steel. Temperature control is of prime importance in keeping corrosion at a minimum. Corrosion can become quite extensive if interior surfaces become cool for any reason. It is therefore recommended that thorough internal inspections be made during the first year of operation. If interior corrosion is noted, some means of correction should be applied as soon as possible. Heat insulation applied to exteriors of the corroded components will normally correct this condition.

In kraft pulp mills, process operations can fluctuate widely. Covering the interior surfaces of side frames, end frames, and roof with gunite will prevent damage to the steel. The corrosive effects can be minimized by installing heat jackets which can be heated by dry air or electric heat.

B.3.10 MAINTENANCE SCHEDULE AND TROUBLESHOOTING

Annual Inspection/Maintenance

Prior to any inspection, it is of utmost importance that the precipitator is de-energized and grounded and the necessary precautions are taken to ensure that the equipment control be energized during the internal inspection.

Dust Accumulations

Observe the dust accumulations on both plates and wires. The discharge wires should have only a slight coating of dust with no corona tufts (doughnut-shaped dust accumulations). Thickness of dust buildup on plates is normally between 1/8 and 1/4 inch. If the plates have more than 1/4 inch of dust, the vibrator-rappers are not cleaning properly.

Discharge Wires

Replace any broken discharge wires, necked-down wires, or fatigued wires to avoid the possibility of breaking during operation. Breakage of just one wire may render an entire precipitator section inoperative. Record the exact location of all wire failures as well as the location of breakage on the wire.

Alignment of Plates and Wires

The plate-to-wire clearance at both top and bottom of plates should not be less than 4-1/2 inches, while the minimum acceptable plate-to-wire clearance at the vertical midpoint of the plates is 4 inches (assuming 9-inch duct spacing). Close electrical clearances create excessive sparking and prevent optimum operation.

High-Tension and Plate Vibrators-Rappers

Check all high-tension and plate vibrators-rappers for misalignment and/or binding of the vibrator-rapper rods through the roof sleeves. Binding in this area prevents transmission of rapper energy to the collecting plates and high-tension discharge wires and results in excessive dust accumulations.

High-Tension Frame Support Bushing

The internal and external surfaces of the high-tension frame support bushing must be maintained free of dust to guard against high-voltage electrode tracking across insulator surfaces. This condition will lead to thermal fracturing of the bushings through heat concentration. Clean all high-voltage insulators and check thoroughly for sign of cracks; replace where necessary. All electrical connections should be secure.

High-Voltage Electrical Control Cabinet

Clean all components of dust accumulation and lubricate where necessary. Replace the ventilating fan filter.

Transformer-Rectifier Sets

Check the oil level in the high-voltage transformer and add the proper oil if necessary. Check all bushings, terminals, and insulators for dust buildup and evidence of electrical tracking. Check the surge arrestor gap setting on the high-voltage transformer and readjust if necessary. Interlocks must also be checked.

Dry Drag Bottom

The pillow block shaft bearing is a double row roller bearing pre-lubed with sufficient lubrication for approximately one year of normal service.

Hoppers

Hoppers are present on electrostatic precipitators servicing bark and combination bark fossil fuel fired boilers. Items to check are dust buildup in the upper corners of hoppers and debris such as fallen wires and weights in the hopper bottom and valves. Inspect anti-sway insulators to see that they are clean and not cracked. If a discharge electrode weight has dropped 3 inches, it indicates a broken wire.

Screw Conveyor

Since the highest torque is transmitted at the drive shaft and conveyor connection, it is recommended that coupling bolts be removed periodically to inspect for widening of bolt holes and bent or worn belts.

Daily Inspection and Readings

Record all control set electrical readings once per shift. Any abnormalities in shift-to-shift readings may well be the first clue of a malfunction within the precipitator. In addition, the daily log should include process operating data, flue gas analysis, verification of transmissometer calibration, and a record of all transmissometer readings.

Vibrators/Rappers

Ensure that all collecting plate and discharge wire (high-tension) vibrators-rappers are functioning properly and operating at the proper intensity level. Lack of vibrating/rapping will result in dust buildup on both the plates and wires, which reduces electrical clearances and necessitates operation of the equipment at reduced power levels. Over vibrating/over rapping of the internals leads to reentrainment of collected dust; therefore, it is important that proper intensity values be used for optimum precipitator performance.

Wet Bottom (Conventional)

Check the temperature of the piping between the wet bottom and the float chamber to detect liquor congealment in the piping.

Hoppers

Thoroughly check all hoppers, particularly the unloading mechanism for proper operation. Overfilling of hoppers can lead to very serious damage of internal components. Check thoroughly for air inleakage at the hoppers. The siphoning of cold ambient air into the hoppers usually results in formation of condensation and agglomeration of dust, resulting in plugging of the hopper.

A troubleshooting chart for an electrostatic precipitator is presented in Table B.3-1.

Frequency of failure of various precipitator components and repair times for a typical industrial precipitator are presented in Table B.3-2.

Table B.3-1. TROUBLESHOOTING CHART FOR ELECTROSTATIC PRECIPITATORS

Symptom	Probable cause	Remedy
Spark meter reads high, primary voltage and current very unstable	Misadjustment of automatic control, loss of limiting control	Readjust automatic control, replace automatic control
Neither spark rate, current, nor voltage at maximum	Misadjustment of automatic control, automatic control not at maximum, failure of signal circuits	Readjust setting of automatic control, readjust automatic control, check signal circuits
No spark rate indication, voltmeter and ammeter unstable, indicating sparking	Failure of spark meter, failure of integrating capacitor, spark counter sensitivity too low	Replace spark meter, replace capacitor, readjust potentiometer on automatic control
No response to current-limit adjustment, response to other adjustments	Controlling on spark rate or voltage limit, failure of automatic control, current signal to automatic control defective	None needed if unit is operating at maximum spark rate or voltage adjustment, reset voltage or spark rate if neither is at maximum, replace automatic control, check signal circuit
No response to voltage-limit adjustment, response to current adjustment	Controlling on current limit or spark rate, voltage signal to automatic control defective, failure of automatic control	None needed if unit is operating at maximum current or spark rate, reset current and spark rate adjustment if neither is at maximum, check voltage circuit, replace automatic control
No response to spark rate adjustment, response to other adjustment	Controlling on voltage or current, failure of automatic control	None needed if unit is operating at maximum voltage or current, reset voltage and current adjustment if neither is at maximum, replace automatic control
Precipitator current low with respect to primary current, low or no voltage across ground return resistors	Surge arresters shorted, H.V. rectifiers failed, H.V. transformer failed, ground or partial ground in the ground return circuit	Reset or replace surge arresters, replace H.V. rectifiers, replace H.V. transformer, repair ground return circuit

(continued)

Table B.3-1 (continued)

Symptom	Probable cause	Remedy
	Transformer-Rectifier Controls	
No primary voltage, no primary current, no precipitator current, vent fan on, alarm energized	D.c. overload, misadjustment of current limit control, overdrive of SCR's	Check overload relay setting, check wiring and components, check adjustment of current-limit control setting, check signal from firing circuit module
No primary voltage, no primary current, no precipitator current, vent fan off, alarm energized	Control panel fuse blown, loss of power supply, circuit breaker tripped	Replace fuse or reset circuit breaker, check supply to control unit, reset circuit breaker
Control unit trips out on overcurrent when sparking occurs at high currents	Overload circuit incorrectly set	Reset overload circuit
High primary current, no precipitator current	Short circuit in primary current, transformer or rectifier short	Check primary power wiring, check transformer and rectifiers
No primary voltage, no primary current, no precipitator current, vent fan on, alarm not energized	SCR and/or diode failure, no firing circuit	Replace, check signal from firing circuit
Low primary voltage, high secondary current	Short circuit in secondary circuit or precipitator	Check wiring and components in H.V. circuit and pipe and guard. Check precipitator for interior dust buildup, full hoppers, broken wires, ground switch left on, ground jumper left on, foreign materials on H.V. frames or wires, broken insulators
Abnormally low precipitator current and primary voltage with no sparking	Misadjustment of current and/or voltage limit controls, misadjustment of firing circuit control	Check settings of current and voltage limit controls
Spark meter reads high-off scale, low primary voltage and current, no spark rate indication	Continuous conduction of spark counting circuit, spark counter counting 60 cycles peak, failure of automatic control	Deenergize, allow integrating capacitor to discharge and reenergize, adjust spark control circuit, replace automatic control

(continued)

Table B.3-1 (continued)

Symptom	Probable cause	Remedy
Primary current and secondary current normal, primary voltmeter drops from normal to zero and remains for a second then jumps back to normal, repeating this sequence rhythmically	Broken wire, swinging frame	Remove broken wire, check for broken anti-away bushings
	Rapper Controls	
Circuit breaker trips	Short circuit or component failure in control circuit or power transformer	Check wiring and component
Fuses blown, indicator light not flashing	Control circuit failure, rapper coil failure, distributor switch firing two coils at once	Replace defective component, replace coil, repair or realign distributor switch
Indicator light not flashing, no fuse failure	Control circuit not operating effectively, no rotation of distributor switch	Repair or replace component, check motor and drive train
No manual intensity control	Failed potentiometer, faulty intensity control module	Replace potentiometer, replace intensity control module
	Vibrators and Controls	
Vibrator inoperative	Vibrator coil open circuited, vibrator improperly adjusted	Replace coil, adjust vibrator
Abnormal ammeter reading	Vibrator improperly adjusted, vibrator coil short circuited	Adjust vibrator, replace coil
Line breaker trips	Short circuit in control wiring	Check circuit

Table B.3-2. FREQUENCY OF FAILURE AND REPAIR TIMES REQUIRED FOR VARIOUS PRECIPITATOR COMPONENTS[a]

	Electrical repair - external -				Mechanical/electrical repair - internal -					
Reliability and repair	Rectifier controls	Transformer	Rapper coil	Pressure fans	Collecting electrodes	Discharge electrodes	Top and bottom high tension frames	Support bushings	Lower high tension stabilizer bars	Rapper shafts
Frequency of failure	Seldom	Seldom	Seldom	Seldom	No failure	5-7 yr[a]	No failure[b]	5-10 yr	Seldom	No failures
Time to repair	1-6 h	1 day	1 h	2 h	1 wk (one section)	1 h		2 h	1 h	
Parts	Stocked	Stocked	Stocked	Not stocked	Not stocked	Not stocked	Not stocked	Stocked	Stocked	Stocked
Complete units	12 wk	12 wk	Stocked	6-8 wk	4-6 wk	1 wk	2 wk			

[a] Average life; replace with collecting electrodes.

[b] Possibly replace with collecting electrodes.

REFERENCES

1. Henderson, J.S., "Precipitator Survey on Non-Contact Recovery Boilers, TAPPI Vol. 58 No. 5, May 1975.

2. Industrial Air Pollution Control, Chapter 7, PEDCo Environmental, Inc., prepared for U.S. Environmental Research Information Center, EPA 625/6-78-004, June 1978.